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Utilizing Glove-Based Gestures and a Tactile Vest Display for Covert Communications and Robot Control

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ARL-TR-6971 **June 2014**

NOTICES

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Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5425

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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED (From - To)
June 2014	Final	July 2013

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Utilizing Glove-Based Gestures and a Tactile Vest Display for Covert Communications and Robot Control	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
Linda R. Elliott, Anna Skinner, Rodger A. Pettitt, Jack Vice, and Alexander Walker	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: RDRL-HRM-DW Aberdeen Proving Ground, MD 21005-5425	8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-6971
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Dismounted Soldiers consistently experience heavy cognitive and visual workload, particularly during navigation and patrol, and under conditions of high stress and time pressure. This report describes an investigation of the potential of gestural controls and a tactile vest display expected to reduce cognitive, physical, and temporal demands as they relate to covert communications and robot control. Data were collected on 31 Soldiers. Twelve Soldiers were from the Explosive Ordnance Disposal military occupational specialty and had extensive experience with robot control. In this experiment-based evaluation, the task demands in a typical rural reconnaissance patrol were deconstructed into specific tasks involving a platoon leader role, a squad leader role, and a robot controller role. Results showed that use of an instrumented glove and a tactile vest display for covert communications was associated with a higher average percentage and faster average speed of signal detections when compared to traditional hand and arm signals. Also, glove-based control of robot maneuvers was compared with a handheld controller. While the glove controller was not associated with better performance outcomes, Soldiers expressed high regard for the concept, and provided many suggestions for further development of gestural controls for both covert communications and robot control.

15. SUBJECT TERMS
gesture control, tactile display, hand and arm signals, human robot interaction, covert communication

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Linda R. Elliott
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(Include area code)*
Unclassified	Unclassified	Unclassified	UU	122	706-545-5634

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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Acknowledgments

The authors would like to thank and acknowledge the contributions of the project managers supporting the effort described in this report: Michael Barnes and Sue Hill (U.S. Army Research Laboratoy/Human Research and Engineering Directorate), with reference to multiyear investigations of human-robot interaction. We also thank all the support staff that collected performance data alongside each Soldier and those who diligently organized and reduced the data. We thank Connie Fore for contributing her professional photographs. We are particularly indebted to the Soldiers who participated readily and steadily throughout this event. Their expert perspective provides great insight with regard to how to best use and improve the advanced controls and displays discussed in this report.

1. Introduction

1.1 Background

1.1.1 Soldier Visual and Cognitive Workload

Human factors studies of Soldier roles have shown significant overloading of the visual and auditory sensory modes in the jobs of Abrams tank commanders and drivers (Mitchell, 2009), ground robot controllers, and unmanned aircraft operators. Dismounted Soldiers consistently experience heavy cognitive and visual workload, particularly during navigation and patrol, and under conditions of high stress and time pressure (Mitchell et al., 2004; Mitchell, 2005; Mitchell and Brennan, 2009a, 2009b; Pomranky and Wojciechowski, 2007). In addition, a review of emerging technologies assessed for infantry Soldier combat teams during the Army Expeditionary Warrior Experiment included aerial and ground vehicles with sensor arrays, small stationary sensors, more robust communication capabilities, and improved visual capabilities encompassing weapon sights, binoculars, night vision, and targeting aids (Scalsky et al., 2009; U.S. Army Evaluation Center, 2013). From this, we see clearly that cognitive task demands on dismounted Soldiers are increasing.

In addition to the cognitive demands placed on dismounted Soldiers, physical and temporal demands are also higher as the complexity of team communications increases. As Soldiers gain and control additional command and control and robotic assets, two primary issues must be addressed. First, there is the challenge of weight and bulk, as these additional assets must be carried. Current control interfaces for unmanned vehicles often significantly increase the weight and quantity of equipment carried by the dismounted Soldier. Second, these controls and displays must be easy to use and understand. This report describes an investigation of the potential of advanced concepts in smaller lightweight wearable displays and controls that are expected to reduce cognitive, physical, and temporal demands as they relate to dismounted Soldier performance. Specifically, we explore concepts of gesture-based controls and tactile displays as a means of covert communications and robot control.

1.1.2 Hands-Free Covert Communications

Soldier communications, within and across teams, are essential for Soldier effectiveness. Communications must be rapid, concise, and immediately understood. However, the use of handheld communication devices poses some challenges. While handheld devices such as radios or more recently, smartphones and smart tablets, provide critical capabilities, these handheld devices can also distract a leader’s visual attention away from the tactical battlefield environment and in some cases, hinder their ability to use their weapons or increase the response time to engage a target when having to transition from the device to the weapon. When the communication is speech-based, there is also the common problem of noisy environments.

Because of this, there will always be situations where the handheld device is best left in the pocket; there will always be the need for Soldier communications that are covert and relatively hands-free, allowing immediate access to weapons.

A fundamental form of this kind of communication among Soldiers is the use of hand and arm signals. Dismounted Soldiers in the field often utilize an established set of hand and arm signals to communicate with others while maintaining noise discipline (e.g., when approaching an objective) or at times when noise levels exceed what can be heard via voice and radio. Most military personnel are familiar with these signals. Soldier hand and arm signals are documented in sources such as the U.S. Army Field Manual No. 21-60 and U.S. Marine Corps Rifle Squad Manual (FMFM 6-5). In addition, certain mission scenarios may have further requirements, such as a need for covert operations (e.g., low noise and/or electronic transmissions) or combat operations characterized by high stress, high time pressure, high noise, low visibility, and/or night operations. These commands are often relayed from one team member to the next, reaching team members not within line of sight of the initial team member issuing the command; however, this takes time and requires aural and visual attention to receive commands. In the next section, we discuss a technology-based alternative to traditional hand and arm signals.

1.2 Gesture-Based Technology

Gesture-based technology offers a promising refinement to traditional Soldier hand and arm signals. Several prototype systems have been developed for different military objectives. These systems can usually be classified by the means by which the gestures are recognized; either through camera-based methods or that of wearable sensors. We will describe a few applications.

1.2.1 Camera-Based Gestures

Cohen (2000, 2005) developed and demonstrated a prototype gesture recognition system for dismounted Soldiers that provided camera-based gesture recognition of signals based on existing Army hand and arm signals. The approach for this technology was developed and demonstrated previously (Cohen, 1997). The purpose was to prove the capability for technology-based recognition of Soldiers using a subset of Army hand and arm signals. The capability was developed to enhance training of gesture-based communications. The system would monitor if the proper gesture was performed adequately and if not demonstrate a proper performance of the required gesture. The system also had a goal of learning new gestures. Dynamic gestures included "slow down," "prepare to move," and "attention." Static gestures included "stop," "right/left turn," "okay," and "freeze." The researchers also used a variety of additional gestures, based on circles and lines, to evaluate recognition performance. Recognition rates varied from 80% to 100%, with many gestures recognized at 95%–100% accuracy. This camera-based approach to recognition of gestures, motion-tracking, and feature matching has been applied to numerous surveillance applications (Cohen, 2013).

Perzanowski et al. (2000a, 2000b, 2002, 2003) reported progress toward using gestures for robot control. Syntactic and semantic information was drawn using ViaVoice and a natural language understanding system, (Wauchope, 1994). Visual cues included body location, eye gaze, or other types of body language. This approach was augmented with use of gestures, such as pointing. In the 2002 instantiation, gesture recognition was based on a camera with a structured light rangefinder mounted to the side of the robot to track the user's hands, while sonar sensors were used to detect objects in the environment. In 2003, a "wizard-of-oz" experiment was conducted to explore naturally occurring preferences with regard to the use of gestures and language syntax. Natural language and spatial relationships were based on an approach described by Skubic et al. (2001a, 2001b, 2002).

There are also efforts to build gesture-based communications for control of aircraft and unmanned aerial vehicles (UAVs). Recent efforts to develop camera vision-based recognition of aircraft handling hand and arm signals have included work by Choi et al. (2008), as well as a current Office of Naval Research (ONR)-funded research and development effort being conducted at the Massachusetts Institute of Technology by Song et al. (2011a, 2011b, 2012). Choi et al. report overall accuracy of 99% for a training set consisting of multiple repetitions of only eight gestures, while Song et al. have demonstrated gesture recognition accuracy of 75.37% for a subset of 24 aircraft handling gestures. In both cases, data were collected within a highly controlled laboratory setting in which lighting was controlled, visual noise was eliminated, an optimized field of view (FOV) and distance to the user were ensured, and hand and arm signals were generated by individuals that were standing still, rather than interacting within a complex and dynamic environment. So while promising, it is not yet determined how well these systems will meet operational needs in challenging circumstances.

Ablavsky (2004) also reported progress towards proof of concept camera-based gesture recognition system for the direction of UAV movements on aircraft carrier decks. The passive camera system used a wide FOV for recognition of blinking beacons and a narrow FOV for observing hand and arm gestures. In contrast, Urban et al. (2004) used a motion tracker along with wearable sensors to accomplish the same task goals. Sensors were attached to armbands worn by the operator. Two sensors on each arm (i.e., upper and lower arm) were determined to be sufficient for most gestures in the Navy gesture lexicon for control of aircraft on the ground. While gestures were accurately recognized, there were problems associated with wired sensors (e.g., tangled wires, necessity of being near the base device) and fatigue associated with bulky sensors, indicating the need for smaller, wireless sensors.

Kennedy et al. (2007), using ViaVoice, programmed speech and gesture commands for a core set of commands relevant to Marine reconnaissance missions: "Attention," "Stop," "Assemble" (i.e., come here), "As you were" (i.e., continue), and "Report" (e.g., assuming the robot can communicate to the user). The first four commands were taken from the U.S. Marine Corps Rifle Squad manual (FMFM 6-5). The robot interacted with a team member through voice, gestures, and movement, using ACT-R (Adaptive Character of Thought-Rational) cognitive architecture

with additional capacity for spatial reasoning and perspective-taking. Together, the team member and robot were tasked to covertly follow and approach a moving target (e.g., another human or robot). The target continually moved to various locations and had a limited FOV in which to spot any followers. The robot had logical reasoning to enable covert approach, such as “if the target is on the north, east, south or west side of an object, it should hide on the opposite side of the object.” While the emphasis of this effort was on spatial reasoning, gestures and speech were used for inter-communications. However, it is not clear from the report as to the extent of user-to-robot communications that were used or successfully interpreted.

Ruttum and Parikh (2010) reported development of a gestural robot control system using core hand and arm signals used by the Marines. They focused on four signals, “come,” “go here/move up,” “stop,” and “freeze” and identified distinguishing factors from arm, hand, and body orientation/velocity/acceleration. Their approach was camera-based with real-time analysis of continuous video based on a Vicon motion detection system. This system is stated to reduce the limitations with regard to background clutter and orientation of the person to the camera. The assessment was conducted in an indoor area measuring 30 × 25 × 9 ft. The subject was tagged with markers that are detected by infrared cameras set up within the room.

1.2.2 Glove-Based Gestures

While the previously described systems rely on camera systems (either mounted external to the user or helmet-mounted), such systems typically require controlled environments and environmental conditions, rendering them less effective or impractical in many outdoor operational settings. An alternative approach is based on wearable instrumented gloves. Instrumented gloves are the most common instantiation of wearable instrumented systems for robot control. The glove concept is congruent for many work situations where operators may already have to wear gloves. Early versions of these gloves were integrated for computer usage, in that the gloves could be used for computer interface actions such as menu selection. However, the reliance on a visual display was somewhat detrimental to performance (Kenn et al., 2007). For robot control, glove-based approaches are usually stand-alone, with the glove sending signals directly for recognition. Earlier instrumented gloves relied on sensors such as bend sensors, which react to changes of finger angles, and sensor electrodes (Karlsson et al., 1998). Others use touch sensors, magnetic trackers, embedded accelerometers, and electromagnetic position sensors with multiple degrees of freedom, to convey information that is then mathematically interpreted. Optical fiber sensors have also been used to detect angular displacements of finger joints (Fujiwara et al., 2013).

While these gloves have core traits in common, each approach has advantages and disadvantages specific to particular task demands. For example, bend sensors can be fragile in adverse environments or repeated use, and only track static postures. Finger touch sensors may move out of position over time. Accelerometers on fingertips and/or the back of the hand rely on precise finger movements/posture. Piezo sensors have also been used (Hu et al., 2009).

While several types of gloves can accommodate static hand postures (positioning), dynamic hand and arm movements are more challenging and/or not possible for effective gesture recognition by some of these instrumented systems. In short, the findings from one type of glove do not necessarily generalize to other types of gloves; they are not equal in capability or usability. However, they do share some common issues as well.

The glove-based approaches have the same core challenge of gesture capture and coding as do the camera-based approaches. Gesture recognition analysis methods for instrumented gloves overlap with approaches taken with camera-based systems: hidden Markov models (Rabiner and Juang, 1986), finite-state machine (Hong, et al., 2000), dynamic time warping (Hu et al., 2009; Wu et al., 2010), and artificial neural networks (Oz and Leu, 2007). Hand and body gestures can be transmitted from a controller mechanism that contains inertial measurement unit (IMU) sensors to sense rotation and acceleration of movement.

Earlier versions of wearable instrumented gloves relied on recognition of static hand gestures, as extrapolated by the glove sensors with regard to hand posture. Gesture recognition was based on specific features of a hand posture that may be somewhat artificial and difficult to replicate across different users. While intuitive in nature, and appreciated by users, the application of glove-based control can be challenging for robot control. Kenn et al. (2007) found that users would naturally look to the robot instead of their hands, thus allowing more attention to robot performance. However, the gestural commands were sometimes misinterpreted, and these misinterpretations had more negative consequence to robot control, compared to other purposes such as using gestures to control a presentation application.

Ellen et al. (2010) offer a concept of operations for use of wireless communication gloves to communicate, plan, and react while wearing Mission-oriented Protective Posture (MOPP) gear (i.e., protective ensemble for chemical and biological threats). While smartphone applications can be useful for Soldier use, touch screen controls are not easily accomplished while wearing MOPP gear that includes heavy gloves. The gloves have magnetic and motion sensors for gesture recognition. Additional glove-based sensors would provide information regarding chemical and biological threat in the immediate area. Other sensors in this concept include GPS, physiological sensors, and video imagery.

A primary advantage of glove-based systems for the dismounted Soldier is the ability to send signals that are out of line of sight (LOS). Camera-based systems have often relied on stationary cameras, sometimes with multiple cameras, in indoor settings where the cameras do not move, lighting is controlled, and participants wear particular colors to enhance recognition. Army operations “in the wild” cannot always accommodate these restrictions, with major issues being mobility and night operations. In some cases, camera-based systems have been mounted on the robot itself; however, they still rely on sufficient lighting conditions and the user being within a visual sector (e.g., range, FOV) for effective recognition. While camera-based systems

have great potential, technology has not advanced to the point where the robot has the capability to “see” and understand. For these reasons, the glove-based approach was chosen for initial investigation with regard to the dismounted Soldier.

Automated electronic capture of hand and arm signals via an instrumented glove enables commands to be sent to all team members simultaneously, without requiring LOS. These electronic commands can be presented to both human and robot team members, and the sensors necessary for gesture recognition can be small, lightweight, and unobtrusively integrated into warfighters’ current field gloves. Hand movements can thus be used for direct and supervisory control of robotic assets, and standard hand signal commands can be presented to human team members via a variety of modalities. IMU sensor technologies placed on the body provide an alternative, technically feasible, near-term approach to gesture recognition within uncontrolled environments. In this way, glove-based devices can allow warfighters to communicate with each other, obtain information, and control remote devices without impeding their ability to perform tasks in a field environment (Vice et al., 2001; 2005).

1.3 Tactile Display Technology

While the instrumented glove provides the means for covert gestural signals out of LOS, the reception of the signals will be accomplished covertly through a torso-mounted vest having an array of vibrating tactors. The tactile modality has proven to be a reliable and covert conduit for the conveyance of critical information during infantry tactical operations. For example, Van Erp (2005) showed that a localized vibration on a waist belt could easily and accurately be interpreted as a direction in the horizontal plane as it is intuitive to infer direction from the torso, which is relatively stable. Meta-analyses of experiments that directly compared tactile displays with visual displays identified circumstances where the tactile modality would be most likely to increase performance (Elliott et al., 2009). Results indicated that tactile display is particularly effective under conditions of high cognitive workload, particularly for attention management, spatial orientation, direction, and critical communications. The torso-mounted tactile displays have proven effective for navigation in field evaluations. These displays, if integrated with GPS, enable dismounted Soldiers to navigate in low visibility conditions, hands-free (allowing the Soldier to hold his/her weapon) and eyes-free (i.e., allowing focused attention to surroundings rather than a visual display) (Elliott et al., 2011; Elliott and Redden, 2013).

Torso-mounted tactile displays have been shown to be effective for dismounted Soldier communications. Pettitt et al. (2006) evaluated the effectiveness of a torso belt that consisted of eight specialized tactors (i.e., Engineering Acoustics Inc.; C2 tactors) arranged equidistant around the waist. Individual or multiple tactors were activated by an operator using a remote wireless control system. Infantry Soldiers, wearing their standard uniforms and body armor, negotiated a woodland individual movement technique (IMT) obstacle course. Tactile and

visual hand and arm signals were sent to the Soldiers as they negotiated the course. The tactile signal patterns were intuitive and easy for the Soldiers to understand; less than 10 min of training was required for the Soldiers to become accurate in interpreting the four tactile signals used during the experiment. Results demonstrated that Soldiers performing IMT were able to receive, interpret, and accurately respond to the tactile commands faster than when the information was passed by leaders in the front of a wedge formation and leaders in the back of a wedge formation using conventional hand and arm signals. Soldiers also commented that they were better able to focus more attention on negotiating obstacles and on area situational awareness when receiving tactile signals than when maintaining visual contact with their leaders to receive standard hand and arm signals.

In the evaluation reported here, we add the instrumented-glove concept to that of a tactile display. The instrumented glove, developed by AnthroTronix, was calibrated to send four different communications to a tactile vest display. The tactile display used in this evaluation was not used for direction cue, but focused on the hand and arm information cues generated by the glove-based system. In this evaluation, the focus was on the capability of the glove to send the signals to the tactile belt, when used by Soldiers performing typical operational movements. The integration of glove and tactile display is expected to reduce cognitive effort and enhance performance, consistent with Wickens' theory of multiple resources (Wickens, 2002, 2008), which posit reduction of workload through distribution across perceptual and cognitive channels, and that of Prenav by van Erp (2007), which discusses the role of preattentional processing in tactile cueing.

1.4 Research Objectives

The goal of this evaluation was to assess concepts and capabilities related to the use of an integrated gestural glove and a tactile vest for Soldier communications. Future concepts include integration of semi-autonomous robotic assets as part of the Soldier squad. For this reason, the glove concept was also applied to simple robot control commands. The system, Communication-based Operational Multi-Modal Automated Navigation Device (COMMAND), integrated an instrumented glove for automated gesture-based communication and control, a tactile display vest, and a GPS-enabled ruggedized handheld computer. The objectives of this study were to (a) identify issues pertaining to Soldier use (e.g., operational relevance) and (b) evaluate usability (human factors assessment) of system components and the system as a whole. Evaluation was situated around task demands characteristics of a rural reconnaissance mission scenario requiring inter-Soldier communications and robot control.

2. COMMAND System for Soldier Communications

The COMMAND system components, shown in figure 1, include a ruggedized instrumented glove, GPS-enabled ruggedized handheld computer, and tactile display vest.

Figure 1. COMMAND system components.

2.1 Instrumented Gloves for Hand and Arm Gestures

The gesture recognition glove used for hand and arm signal detection for communication among Soldiers consisted of a standard tactical glove with accelerometers embedded within each finger, and an accelerometer, gyroscope, and digital compass embedded in the back of the hand as shown in figure 2. Figure 3 shows the system as worn by a Soldier.

Figure 2. Instrumented ruggedized tactical glove used for Soldier communication.

Figure 3. Soldier wearing instrumented glove for hand and arm signals.

2.2 Handheld Computer

Data processing and signal communication were performed by two TDS Nomad GPS-enabled ruggedized handheld computers (one carried by the individual generating hand signals and one carried by the individual receiving communications via the haptic vest). The handheld computers included touchscreen and visual displays, an Android operating system, custom gesture recognition software and tactor controller software, as well as embedded GPS and wireless communication capabilities (figure 4).

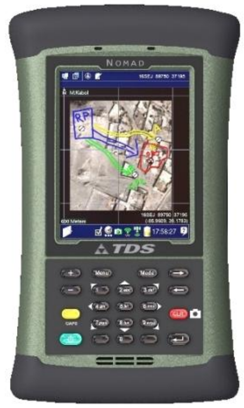

Figure 4. TDS Nomad handheld computer.

2.3 Tactile Vest

The tactile feedback vest consisted of a custom-made, ruggedized, adjustable harness with six embedded vibrotactile actuators (tactors) on the front interface, six tactors on the back, and eight spaced evenly around the waist (figure 5). Figure 6 shows the system as worn by a Soldier.

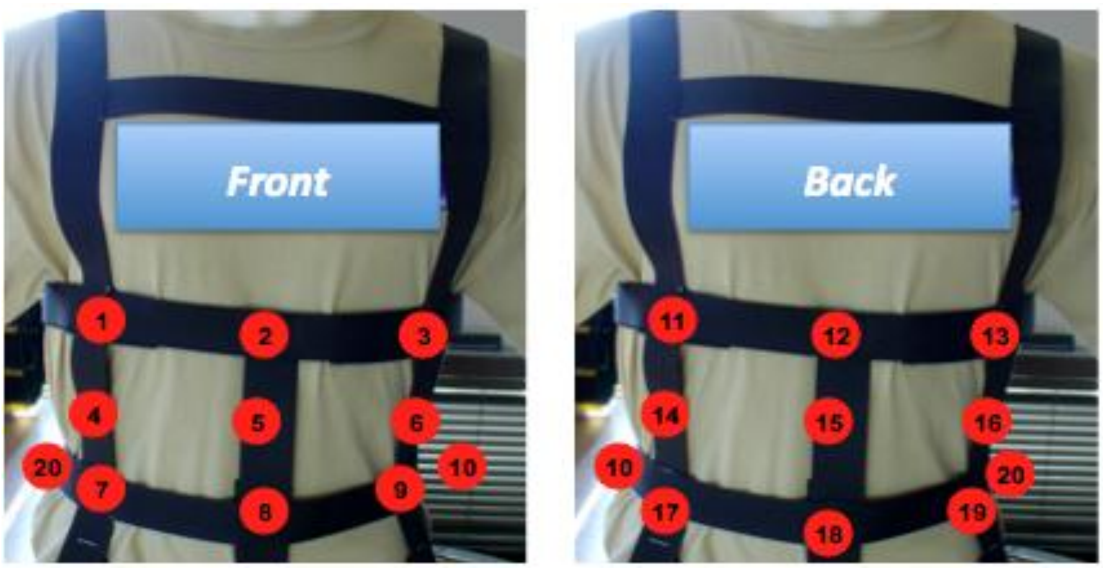

Figure 5. Front (left) and back (right) diagrams of tactile vest and placement of embedded tactors.

Figure 6. Tactile vest worn by Soldier.

This vest design was developed under a previous ONR funded effort, and consisted of a custom tactor solution, using original equipment manufacturer tactor motors and a custom electronics board. The Precision MicroDrive 310-101, shown in figure 7, was found to provide optimal performance within a small form factor and for a cost-effective price point. The tactor control electronics stack favored flexibility of use in a variety of applications as is necessary in a laboratory setting. With a wired universal serial bus (USB) implementation and a 6 V wall transformer power source, it can operate a large number of tactors (up to 32) and has analog input capabilities for auxiliary sensors. This board consists of a single and compact circuit board, including the following circuitry components:

- Microchip PIC (programmable integrated circuit) microcontroller
- Variable duty cycle drivers for 20 tactor motors (I2C pulse width modulation peripheral intensity controllers)
- Integrated wireless Bluetooth communication module

- 3.6 V Lithium-ion battery charging circuit (dual input USB/alternating current adaptor input charging chip with light-emitting diode charge status indicator)
- Battery to regulated 3.3 V power conversion

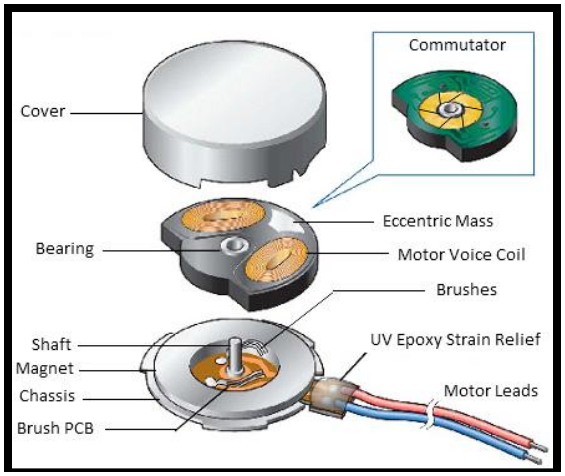

Figure 7. Precision MicroDrive 310-101.

Under this configuration, a single tactor motor running continuously will draw approximately 35 mA, and the tactor circuitry described previously will draw approximately 60 mA when it is receiving wireless data. Assuming a 30%–50% duty cycle, a 1200-mAH Lithium-Ion battery would allow the tactor system to operate for approximately 3–5 h.

2.4 Gestural and Tactile Cues for Covert Communication

For this event there were four hand and arm signals used to test the COMMAND system. One of the four signals (freeze) followed standard Army guidelines while the other three (rally, double-time, danger area) were created to demonstrate the generative capability of the signals used in the COMMAND system. Figures 8–11 provide examples of the glove used during the hand and arm signals task, as well as the specific signals that the Soldiers used.

Figure 8. Hand gesture (left) and diagram of tactile vest activation pattern (right) for "rally."

Figure 9. Hand gesture (left) and diagram of tactile vest activation pattern (right) for "double-time."

Figure 10. Hand gesture (left) and diagram of tactile vest activation pattern (right) for "freeze."

Figure 11. Hand gesture (left) and diagram of tactile vest activation pattern (right) for "danger area."

3. Robot Control System

The robot control system used an instrumented glove for gestural control. Figure 12 shows a Soldier using the glove-based system.

Figure 12. Soldier using instrumented glove for robot control.

3.1 Robot Control Glove and Gestures

The Acceleglove, a commercial off-the-shelf (COTS) instrumented glove developed by ATinc was used within the robotic control tasks and was compared to a traditional gamepad controller. The individual system components are described in detail in the following paragraphs.

The Acceleglove consisted of a nylon glove with the finger tips exposed, having accelerometers embedded within each finger and on the back of the hand as shown in figure 13.

Figure 13. Acceleglove
sensor placement
diagram.

The robot control tasks consisted of maneuvering the robot through a series of paths and obstacles, driving both forward and backward, as well as approaching an object, coming as close to it as possible without coming in contact. Thus, the necessary controls included forward, reverse, left, right, and stop. Forward control was activated by angling the hand downward (figure 14); reverse control was activated by angling the hand upward (figure 14); left turning was activated by flexing the index finger (figure 15); and right turning was activated by flexing the middle finger (figure 15).

Figure 14. Forward robot control (left) and reverse robot control (right).

Figure 15. Left turn robot control (left) and right turn robot control (right).

The robot was within view of the participants at all times during task completion; therefore, visual feedback was provided by viewing the robot directly, rather than via a visual or haptic feedback display.

3.2 Baseline Robot Controller

The traditional controller used for comparison to the Acceleglove within the robot control tasks was a COTS gamepad (figure 16) with thumb joysticks and binary buttons.

Figure 16. Standard OCU for robot control.

3.3 Robot

The robot used was the “Urbie” (shown in figure 17). Urbie is a dual tracked, skid steer mobile robot that was developed as a precursor to the Packbot series of robots manufactured by iRobot. The robot has motorized "flipper style" arms that can be used to help the robot navigate over uneven terrain other robots would find difficult. Movement is provided by three 90-W direct current motors, which independently power the Urbie’s tracks allowing for zero-point turning. For this experiment, the Urbie was fitted with a class 1 Bluetooth module to allow for wireless communication with the operator control unit (OCU).

Figure 17. Urbie robot.

4. Experiment Method

4.1 Participants

Thirty-six Soldiers were recruited from the 11 Bravo (Infantry) or similar military occupational specialty (MOS). The voluntary, fully informed consent of all participants was obtained as required by Code of Federal Regulations (CFR) 219 (1991) and Army Regulation (AR) 70-25 (1990) (see appendix A., Informed Consent Form). The investigators adhered to the policies for the protection of human subjects as prescribed in AR 70-25. All participants read and signed a Volunteer Agreement Informed Consent Form (see appendix A). Participants did not receive any compensation for participating in this investigation.

Data were collected on 31 Soldiers; attrition was due to external factors (e.g. weather, equipment). Twelve Soldiers were from an Explosive Ordnance Disposal (EOD) MOS and had extensive experience with robot control. Six Soldiers were from an active Infantry unit (3rd Infantry Division). The remaining Soldiers were from the Officer Candidate School; some had previous military experience while some did not. Length of military service ranged from 7 to

114 months, with rank ranging from E-1 (1) to E-6 (1), with most being E-4 or E-5. Participants included 25 males and 6 females. Twenty-eight were right-handed or ambidextrous. Additional descriptive demographic data are provided in the appendix B.

4.2 Experiment Scenario Tasks

In this experiment-based evaluation, the task demands in a typical rural reconnaissance patrol were deconstructed into specific tasks to better structure the data collection and performance measurement processes. Task demands were organized for two data collection stations, one that included a platoon leader (PL) role and a squad leader (SL) role, and another that focused on a robot controller (RC) role.

The PL role was relatively passive but enabled the participant to use the COMMAND communications unit. The PL walked behind the SL and used the instrumented glove to send communications to the SL, who in turn received the signals via the tactile vest array. In the baseline manipulation, the PL performed traditional hand and arm signals, and the SL would perceive and recognize them visually (e.g., by turning and looking).

The RC role had the participant wear the instrumented gesture recognition glove to control robot movement and performance. The robot was routed through four robot control courses to assess different robot control maneuvers.

Training was accomplished prior to each station event. Each Soldier was introduced to the equipment and demonstrated understanding and use of the equipment prior to the experiment session. Training evaluation information was collected during data feedback sessions. Further detail on each station follows.

4.2.1 Station 1: Covert Communication During IMT and Tactical Movement

Station 1 compared the glove/tactile system with traditional hand and arm signals during tasks associated with Soldier movement. Data included (a) whether the Soldier perceived a signal, (b) the time taken to notice a signal, and (c) accuracy of signal interpretation. In addition, during the tactical movement phase, the number of flags noticed by the Soldiers was also collected.

4.2.1.1 Individual Movement Technique (IMT) Phase

Soldiers used the two systems to communicate while performing standard IMT maneuvers, such as walking, climbing, and crawling. The Soldier acting as the SL would perform these movements, while the Soldier acting as the PL would follow behind the SL and provide either glove-based tactile or traditional hand and arm signals. Figure 18 shows pictures of the hand and arm condition. It is clear that many hand signals generated by the assigned leader (shown here giving the freeze command) can easily be missed by the designated point man (walking ahead) or not seen for several seconds. The SL must visually scan for the hand and arm signals.

Figure 18. Hand and arm signaling during IMT maneuvers.

Figure 19 shows the glove-based condition for IMT maneuvers, which enabled hand signals generated by the assigned leader (shown here giving the freeze command) to be perceived by the designated point man (walking ahead) immediately and without turning around.

Figure 19. Glove-based signaling during IMT maneuvers.

4.2.1.2 Tactical Movement

During this phase, the Soldier acting as the SL was guided through 400 m of wooded terrain by one experienced data collector. One data collector provided the glove-based signals and the other recorded performance data. Each SL traversed 200 m with the glove system, and 200 m with traditional hand and arm signals. Figure 20 shows the SL as he walks ahead, through the terrain. Figure 21 shows the signaling provided by the data collector. Using the instrumented glove and vest on the navigation course enabled hand signals generated by the (PL) to be perceived by the SL immediately and without turning around while navigating in wooded terrain and looking for hidden flag markers. Without the glove and vest, the SL was required to turn around often (shown in photo on right in figure 21) while navigating and looking for flags to detect the generated hand signals.

Figure 20. Soldier performing the SL role during tactical movement.

Figure 21. Data collector providing glove and hand and arm signals during tactical movement.

4.2.2 Station 2: Robot Control

Station 2 was used to evaluate robot control performance using the instrumented glove and a more traditional handheld baseline controller. Data included (a) time and (b) driving errors. There were four robot control tasks:

1. Zigzag course. The robot was maneuvered between two engineering tapes outlining a zigzag pattern. The operator was required to keep the robot within the tape while accomplishing the course (figure 22).
2. Narrow gap course. The robot was maneuvered through a gap created by engineering tape, while avoiding small flags that are situated on and around the direct route (figure 23). The robot was maneuvered from start to finish, going forward, then from the finish point back to the beginning, by going backwards.
3. Figure-8 course. The robot was maneuvered around logs in a figure-8 pattern. The robot would have to move around the left of one log, the right of the next log, and so on, turning around the last one, and continuing the pattern back, going backwards (figure 24).
4. Movement to contact. The robot was maneuvered forward towards a pole and would stop as close as possible. It was then directed backwards, to another pole, also to stop as close as possible (figure 25).

Figure 22. EOD specialist using instrumented glove to control robot maneuvers on the zigzag course.

Figure 23. “Narrow gap” robot control course.

Figure 24. “Figure-8” robot control course.

Figure 25. “Movement to contact” course.

4.3 Experiment Design

4.3.1 Orientation

Each Soldier participant was briefed on the purpose of the investigation, the procedures to be followed during the study, and any risks involved in their participation. To ensure the voluntary nature of participation, copies of the Informed Consent Form were provided to all participants. The investigator explained the contents of the Informed Consent Form. Soldiers were given an opportunity to review the experiment objectives, have any of their questions answered by the investigators, and then were asked to sign the consent form indicating their informed voluntary consent to participate. The participants were informed that if they choose not to participate, they could convey that choice privately to the experimenter. All Soldiers agreed to participate. A demographic questionnaire was then administered to obtain pertinent information on his/her background.

Soldiers were assigned a unique roster number (example, the first day Soldiers were 1–6, the second day were 7–12, the third day 13–18, the fourth day was 19–24, and so on). Table 1 shows how each set of six Soldiers was assigned to each of the three roles (PL, SL, and RC) during a particular day. This ensured that each Soldier participated at each station, for each role, in a counterbalanced order.

Table 1. Assignment of roster numbers to each of three roles (PL, SL, RC).

Roster No.	**Iteration**		
	1	**2**	**3**
1, 7, 13, 19, 25, 31	PL	SL	RC
2, 8, 14, 20, 26, 32	SL	RC	PL
3, 9, 15, 21, 27, 33	RC	PL	SL
4, 10, 16, 22, 28, 34	RC	PL	SL
5, 11, 17, 23, 29, 35	PL	SL	RC
6, 12, 18, 24, 30, 36	SL	RC	PL

4.3.2 Experiment Schedule

Table 2 shows how, based on the matrix in table 1, each Soldier was assigned to scheduled events, counterbalanced for order. Roster numbers were assigned within cells.

Table 2. Schedule for each day by roster number.

Session	Roster 1	Roster 2	Roster 3	Roster 4	Roster 5	Roster 6
Orientation						
0830	Station1-PL	Station1-SL	Station2-RC	Robot control survey		
0930	Feedback session			Station2-RC	Station1-PL	Station1-SL
1100	Station1-SL	Station2-RC	Station1-PL	Feedback session/lunch		
1200	Feedback session/lunch			Station1-PL	Station1-SL	Station2-RC
1330	Station2-RC	Station1-PL	Station1-SL	Feedback session		
1430	Feedback session			Station1-SL	Station2-RC	Station1-PL
1530	Robot control survey			Feedback session		

4.3.3 Post-Session Evaluations

After performing each station role, Soldiers filled out questionnaires to provide feedback regarding the COMMAND system components with regard to ease of use, perception, and interpretation. This was done by independent ratings for each system component and forced-choice rankings. In addition, Soldiers also provided ratings of workload using the National Aeronautics and Space Administration task load index (NASA TLX), ratings of operational utility for different combat missions, and responses to open-ended requests for comments, suggestions, and issues relevant to system performance in the field. Details of the forms are included in appendix B and results of the questionnaires are provided in appendix C.

5. Results

5.1 Covert Communications

The following section provides comparative analyses on detecting the four communication signals provided by the glove via a tactile vest, as compared to visual recognition of traditional hand-arm signals. Both systems were used by Soldiers in two performance scenarios: (a) IMT maneuvers, which occurred when the Soldiers were performing IMT maneuvers such as climbing or crawling, and as when they were walking between IMT obstacles, and (b) tactical movement, when they were following a 400-m path (i.e., two 200-m legs) through a forested field, while searching for visual targets.

5.1.1 Detection Rate, Accuracy, and Time (N= 31)

Table 3 describes signal detection rate, time (seconds), and accuracy rate for the glove/tactile vest and the hand and arm signal conditions, by type of course (IMT versus tactical movement). The detection rate represents the percentage of commands that were detected by the Soldier, time represents the time to detect, and the accuracy rate represents the percentage of those detected, which were correctly identified. In some runs, only two of four signals were working. Problems were associated with the danger and double-time signals, for five of the first ten Soldiers. After

that, signal function became more stable. If the signal was not working, those data cells were left blank. Table 3 provides mean signal detection rate, time, and accuracy for the glove/tactile vest and hand and arm presentations.

Table 3. Mean values for detection rate, time to detect, and accuracy for the glove/tactile vest and the hand-arm condition, during IMT maneuvers and tactical movement.

Course	Glove/Tactile Vest			Hand and Arm		
	Mean Detect (Std. Dev.)	**Mean Time (Std. Dev.)**	**Mean Correct (Std. Dev.)**	**Mean Detect (Std. Dev.)**	**Mean Time (Std. Dev.)**	**Mean Correct (Std. Dev.)**
IMT	1.00[a] (0.0)	2.01[a] (0.38)	0.87 (0.16)	0.88[a] (0.15)	3.70[a] (0.57)	0.95 (0.12)
Tactical Movement	1.00[a] (0.00)	1.89[a] (0.64)	0.95 (0.20)	0.84[a] (0.15)	4.26[a] (0.50)	0.87 (0.16)

[a]p less than 0.01.

The repeated-measures analysis of variance (ANOVA) program by Statistical Package for the Social Sciences was used to analyze specific comparisons within the IMT and tactical movement task demands. We reported the F statistic associated with degrees of freedom (df), the p-value, and the partial eta square measure of effect size ($\eta\rho^2$).

For detection of signals, the difference between glove and hand-arm means were significantly different in the IMT condition (F 1, 30 = 20.13, $p = 0.00$, $\eta\rho^2 = 0.40$) and also for tactical movement, (F 1, 30 = 36.25, $p = 0.00$, $\eta\rho^2 = 0.547$), where detection rates were higher for the glove/tactile system. Figure 26 provides a graph representing the difference pertaining to detection rate for the glove/tactile system versus traditional hand and arm signals for the IMT and tactical movement task demands.

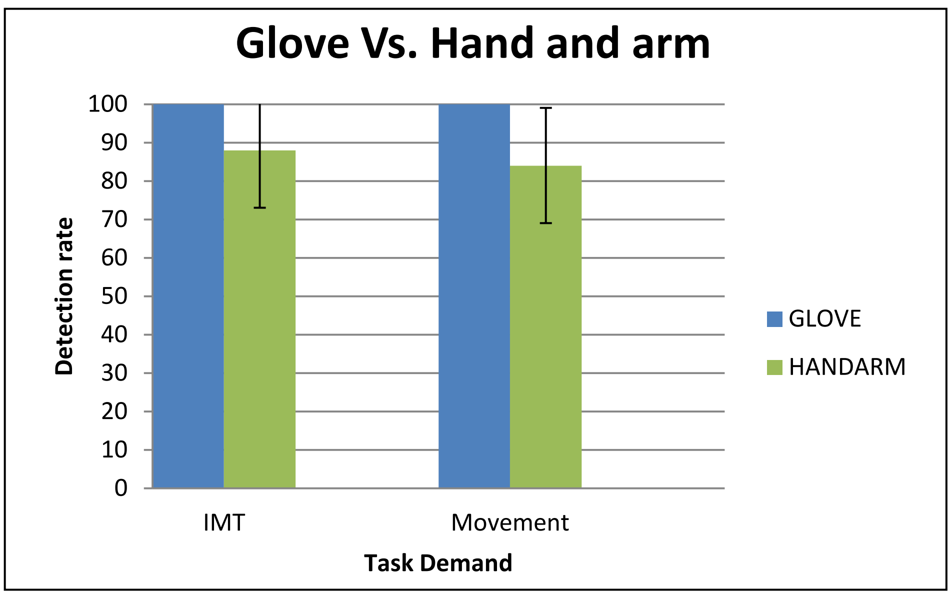

Figure 26. Detection rate using the glove/tactile system vs. hand and arm signals, for IMT and tactical movement. (Error bars represent one standard deviation above and below the mean.)

Differences between the systems in time for detection were also significant for IMT maneuvers (F 1, 30 = 214.84, $p = 0.00$, $\eta\rho^2 = 0.877$) and tactical movement (F 1, 30 = 455.479, $p = 0.00$, $\eta\rho^2 = 0.938$) and can be seen in figure 27.

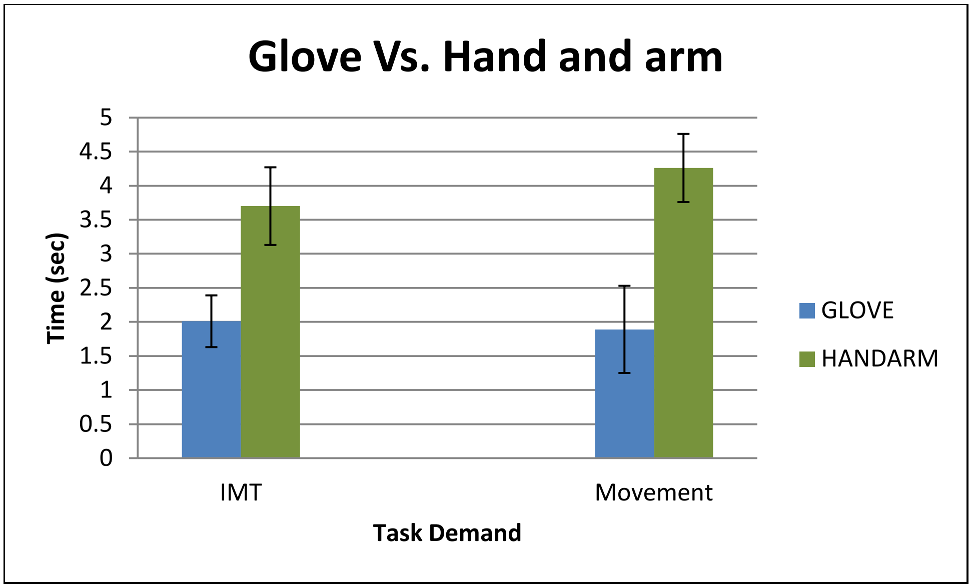

Figure 27. Time to detect signal using the glove/tactile system vs. hand and arm signals, for IMT and tactical movement. (Error bars represent 1 standard deviation above and below the mean.)

Differences in accuracy rate were not significant for IMT tasks (F 1, 30 = 3.95, $p = 0.056$, $\eta\rho^2 = 0.116$) or for tactical movement (F 1, 30 = 0.616, $p = 0.439$, $\eta\rho^2 = 0.02$). These effects are represented in figure 28.

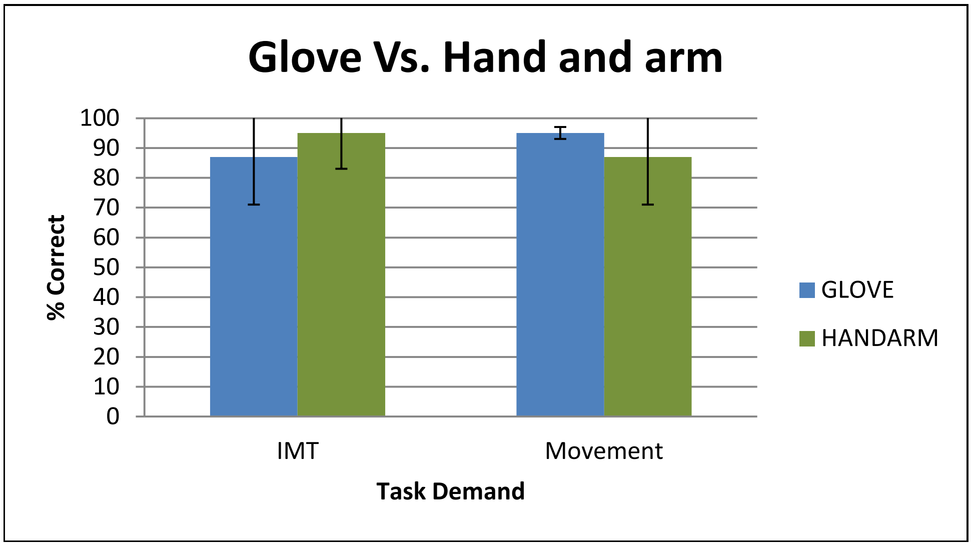

Figure 28. Percent correct signal identification using the glove/tactile system vs. hand and arm signals, for IMT and tactical movement. (Error bars represent 1 standard deviation above and below the mean.)

5.1.2 Breakdowns by Type of IMT Maneuvers

Signals were presented to Soldiers during an obstacle event (e.g., climbing, crawling, combat roll, running) and between obstacles (i.e., walking). The following analyses are for each task demand between these two types of control.

Table 4 provides the descriptive statistics for glove/tactile vest system versus hand-arm signals, for IMT task demands and for tactical movement. With the glove/tactile system, there was no difference between mean detection rate (both 100%) or mean time, due to type of task event (i.e., walking versus obstacle events). The percentage of correct identifications was somewhat lower with obstacle events, while with the hand and arm condition, the effect was that of lower detection rates associated with obstacle events.

Table 4. Mean performance measures by system and type of movement.

Course	Glove/Tactile Vest			Hand and Arm		
	Mean Detect% (Std. Dev.)	Mean Time (Std. Dev.)	Mean Correct% (Std. Dev.)	Mean Detect% (Std. Dev.)	Mean Time (Std. Dev.)	Mean Correct% (Std. Dev.)
Walking	100 (0.0)	2.03 (0.60)	0.92 (0.27)	0.94 (0.23)	3.46 (1.08)	0.96 (0.20)
Obstacle	100 (0.0)	1.92 (0.60)	0.85 (0.36)	0.82 (0.39)	3.82 (1.19)	0.94 (0.23)
Tactical Movement	1.00 (0.00)	1.89 (0.64)	0.95 (0.20)	0.84 (0.15)	4.26 (0.50)	0.87 (0.16)

Differences between the glove/tactile system and the hand and arm signals are similar to overall results, in that the glove/tactile vest system was associated with higher detection rates and faster times. In this breakdown, we examine the extent to which the glove/tactile system was affected by the task demand.

5.1.3 Effects of Task Demand on Performance Measures

Time to detect signal. For the glove system, the differences in time due to task demands were not significant (F 2, 60 = 2.379, $p = 0.101$, $\eta\rho^2 = 0.07$). Differences between the glove/tactile system and the hand and arm signals reflect the same significant trends found between the IMT and the tactical movement tasks (figure 29).

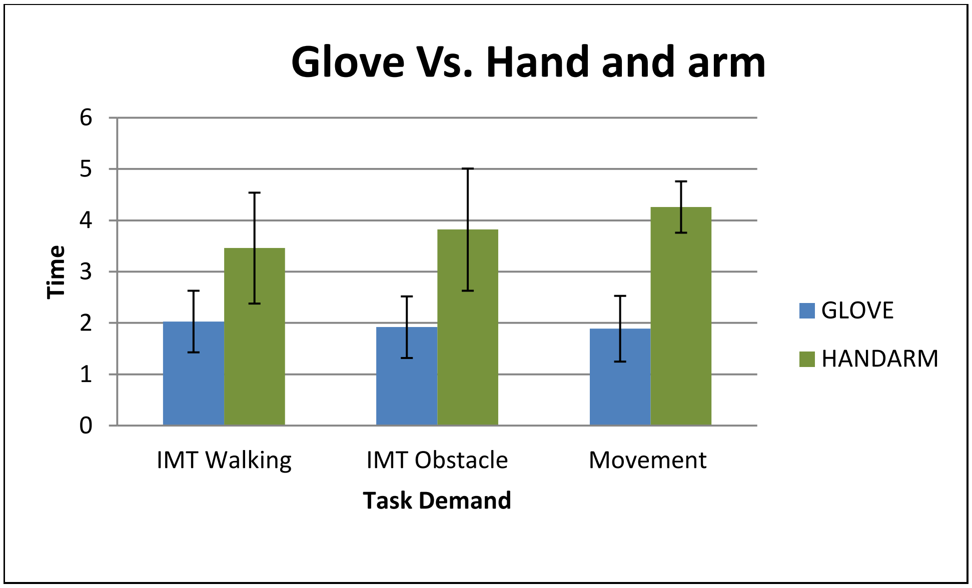

Figure 29. Time to detect signals using the glove vs. hand and arm signals, for IMT walking, IMT obstacles, and tactical movement. (Error bars represent one standard deviation above and below the mean.)

<u>Effect of task demand on detection rate when using the glove/tactile system.</u> There was no difference in detection rate; all conditions were associated with 100% detection. Figure 30 provides the results of the glove/tactile system and the hand and arm signals by condition.

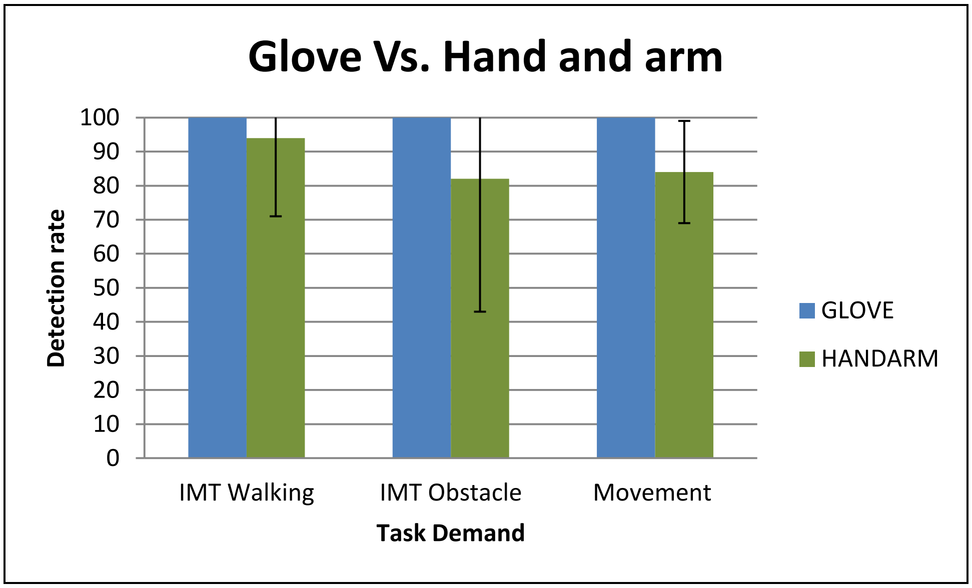

Figure 30. Signal detection rates using the glove vs. hand and arm signals, for IMT walking, IMT obstacles, and tactical movement. (Error bars represent 1 standard deviation above and below the mean.)

Accuracy. The differences in time due to task demands were not significant ($F_{2, 60} = 1.74$, $p = 0.185$, $\eta\rho^2 = 0.06$). Differences between the glove/tactile system and the hand and arm signals reflect the same significant trends found between the IMT and the tactical movement tasks. Figure 31 provides the mean accuracy values for both systems, by task demand.

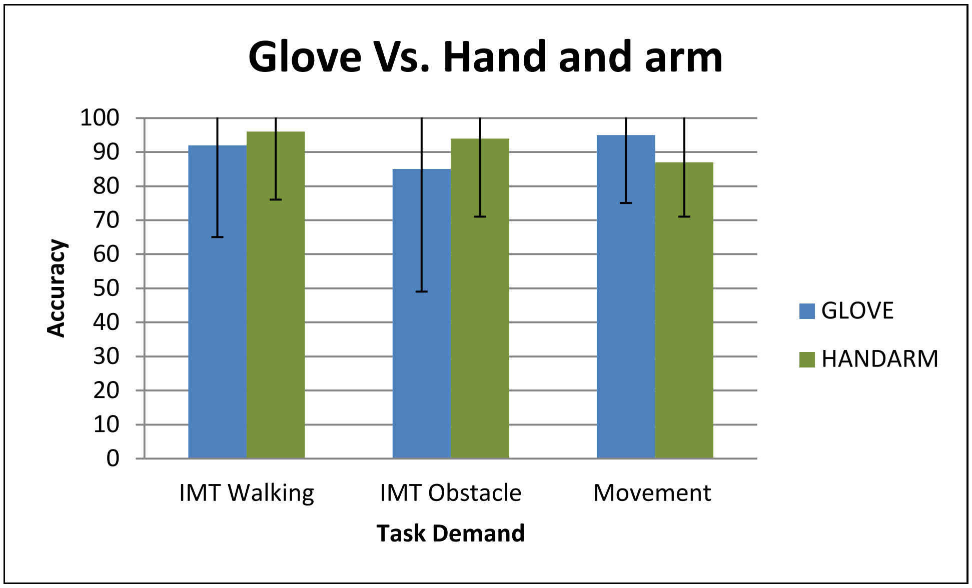

Figure 31. Percent of signals correctly identified using the glove/tactile system vs. hand and arm signals, for IMT walking, IMT obstacles, and tactical movement. (Error bars represent 1 standard deviation above and below the mean.)

5.1.4 Performance by Tactile Signal

Table 5 provides a breakdown of performance values by course (IMT walking, IMT obstacle, tactical movement) and signal (danger, freeze, rally, double-time). Signals for "danger" and "double-time" were associated with higher errors during IMT maneuvers.

Table 5. Mean performance measures by system and type of signal.

Course	Glove/Tactile Vest			Hand and Arm		
	Mean Detect 1.00 = 100% (Std. Dev.)	**Mean Time (Std. Dev.)**	**Mean Correct% 1.00 = 100% (Std. Dev.)**	**Mean Detect% 1.00 = 100% (Std. Dev.)**	**Mean Time (Std. Dev.)**	**Mean Correct% 1.00 = 100% (Std. Dev.)**
Walking						
Danger	1.00 (0.0)	2.25 (0.46)	0.75 (0.46)	0.92 (0.28)	3.42 (1.03)	0.97 (0.17)
Freeze	1.00 (0.0)	1.92 (0.70)	0.96 (0.20)	0.92 (0.27)	3.96 (1.30)	0.92 (0.28)
Rally	1.00 (0.0)	2.10 (0.56)	0.96 (0.18)	0.97 (0.17)	3.37 (1.04)	1.00 (0.0)
Double-time	1.00 (0.0)	2.00 (0.46)	0.90 (0.31)	0.96 (0.19)	3.15 (0.83)	0.92 (0.27)
Obstacle (Combat Roll, High Crawl, Kneeling, Low Crawl)						
Danger	1.00 (0.0)	2.00 (0.60)	0.75 0.45	0.77 (0.42)	4.35 (1.04)	1.00 (0.0)
Freeze	1.00 (0.0)	1.73 (0.45)	0.92 (0.28)	0.89 (0.32)	3.16 (0.85)	1.00 (0.0)
Rally	1.00 (0.0)	2.06 (0.70)	0.85 (0.36)	0.76 (0.44)	3.86 (1.32)	0.95 (0.21)
Double-time	1.00 (0.0)	2.00 (0.60)	0.76 (0.44)	0.83 (0.38)	4.17 (1.23)	0.83 (0.38)
Tactical Movement						
Danger	1.00 (0.0)	2.26 (0.57)	0.88 (0.33)	0.87 (0.34)	4.27 (0.98)	0.96 (0.19)
Freeze	1.00 (0.0)	1.77 (0.56)	1.00 (0.0)	0.84 (0.37)	4.27 (1.14)	0.71 (0.46)
Rally	1.00 (0.0)	2.08 (0.58)	0.97 (0.18)	0.82 (0.38)	4.07 (0.96)	0.96 (0.19)
Double-time	1.00 (0.0)	1.38 (0.53)	0.96 (0.20)	0.79 (0.41)	4.37 (1.05)	0.90 (0.31)

<u>Differences in glove/tactile signal detection due to signal.</u> Detection of signals using the glove/tactile system was 100% regardless of signal (i.e., tactile pattern), across all task demands.

<u>Differences in glove/tactile signal time to detect, due to signal.</u> Figure 32 provides mean time to detect each glove/tactile system signal. Repeated measures ANOVA showed overall significant differences in time to detect due to signal ($F_{3,\,66} = 14.55$, $p = 0.00$, $\eta\rho^2 = 0.40$). Using the Holm's Bonferronni correction for multiple comparisons, all paired comparisons were significantly different, except for the difference between "freeze" and "double-time." Table 6 provides the post-hoc paired-comparison results.

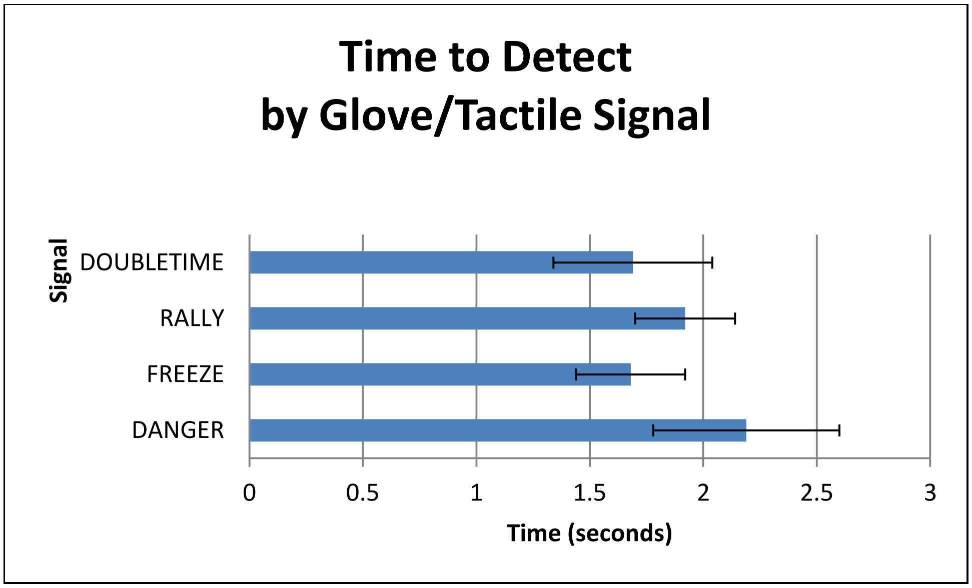

Figure 32. Mean time to detect using the glove/tactile system, for each signal.

Table 6. Paired comparison of glove/tactile signals (time to detect) with Holm's Bonferroni criterion values.

Paired Comparison	Obtained "t"	df	P Sig	Required P Sig
Danger/Double-time	4.66	22	0.00[a]	0.008
Danger/Freeze	4.50	23	0.00[a]	0.01
Rally/Freeze	4.30	29	0.00[a]	0.0125
Danger/Rally	2.92	23	0.01[a]	0.017
Rally/Double-time	2.77	23	0.01[a]	0.025
Freeze/Double-time	0.70	23	0.49	0.05

[a]Significant using the Holm's Bonferroni criteria.

<u>Differences in glove/tactile signal accuracy rate, due to signal.</u> Figure 33 provides mean accuracy rate for each glove/tactile system signal. Repeated measures ANOVA showed no overall significant differences in time to detect due to signal (F 3, 66 = 1.18, p = 0.32, $\eta\rho^2 = 0.05$).

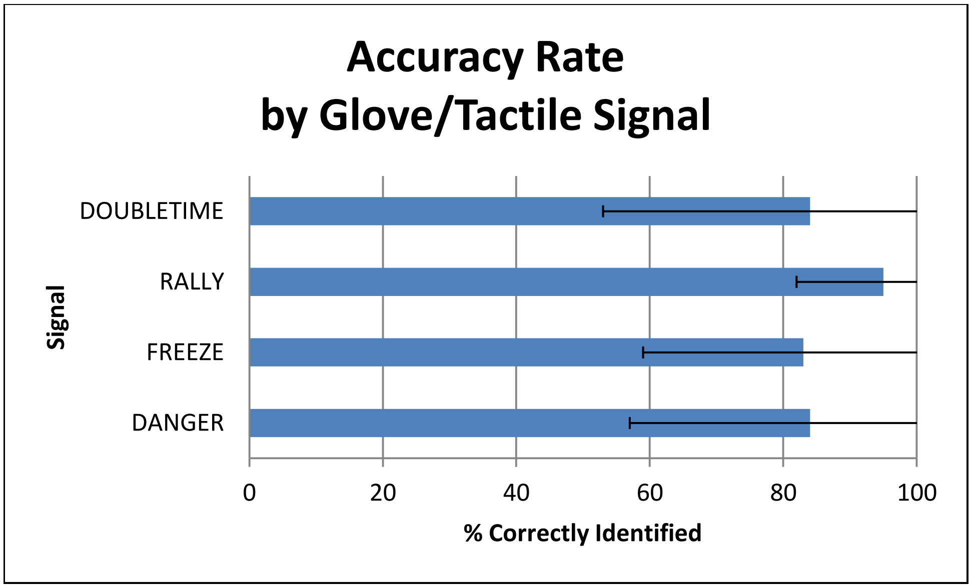

Figure 33. Mean accuracy rate by signal.

<u>Impact of task demand on correct identifications of glove/tactile system signals.</u> Figures 34–36 show the detection rates (i.e., all are 100%) and accuracy rate of each signal by task demand. Accuracy rates remained high regardless of task demand, though rates were somewhat lower when negotiating IMT obstacles. Table 7 provides a breakdown by signal cue, of the type of error made (i.e., what commands were associated with each error).

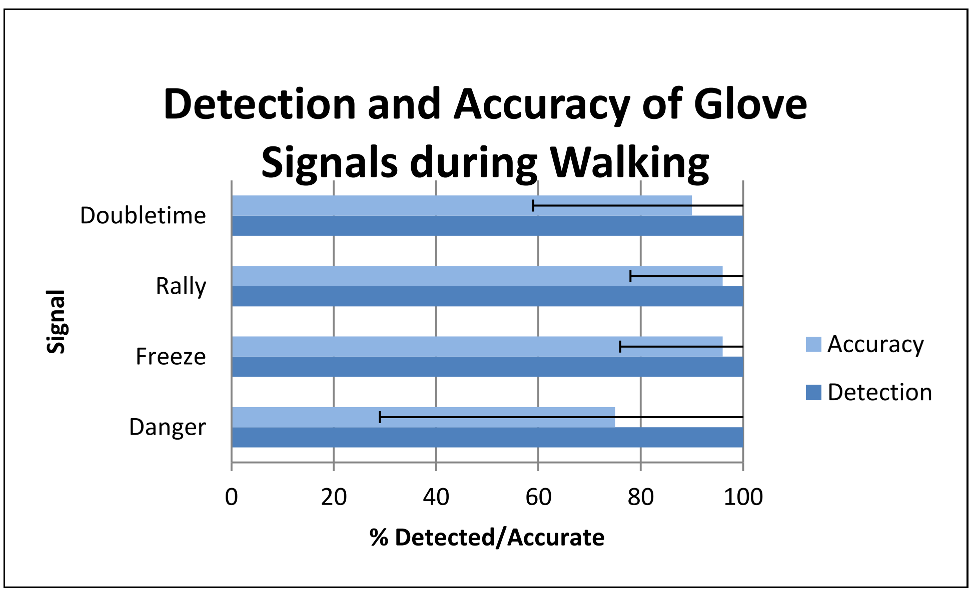

Figure 34. Detection and accuracy rates while walking the IMT course, by signal.

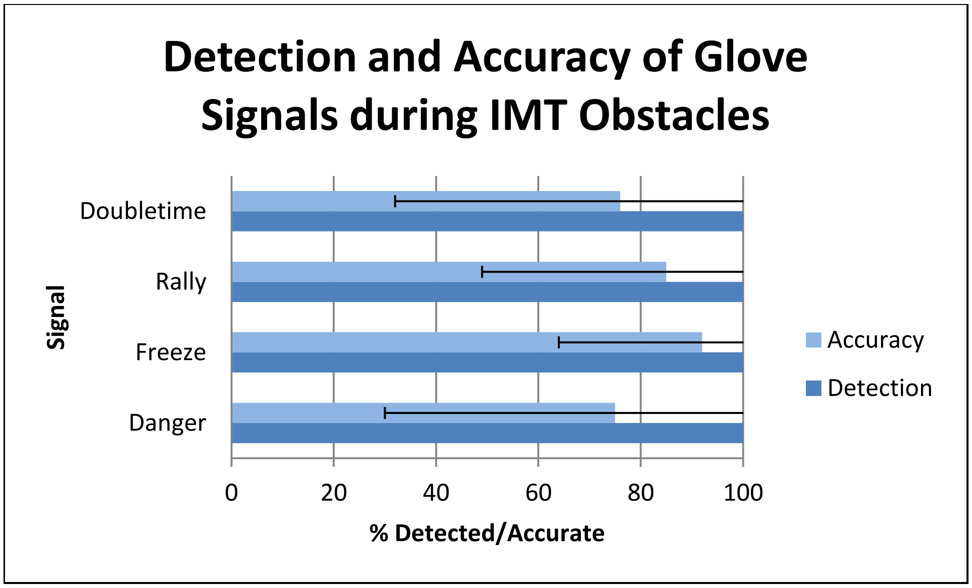

Figure 35. Detection and accuracy rates while negotiating IMT obstacles, by signal.

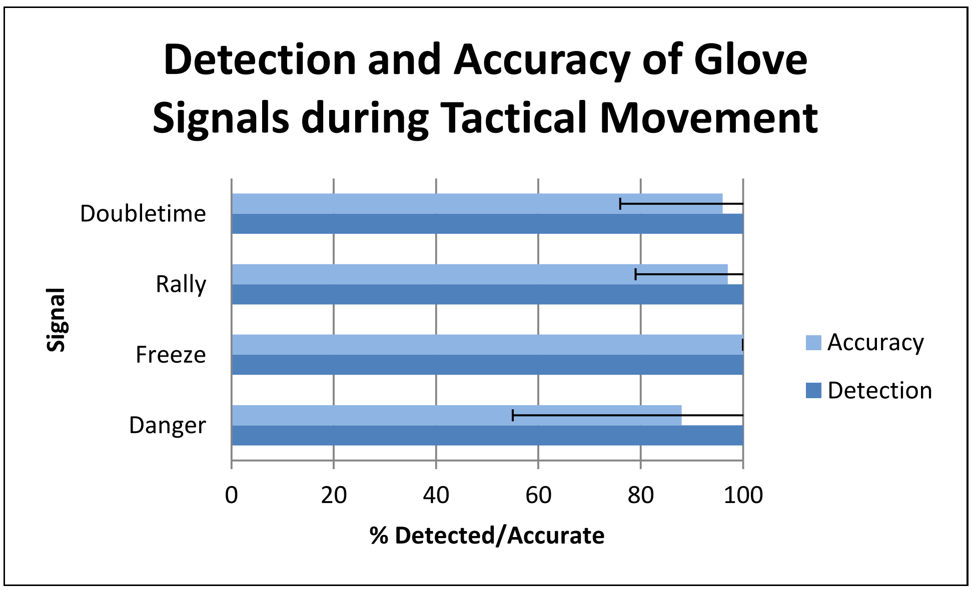

Figure 36. Detection and accuracy rates while walking during tactical movement (e.g., associated with visual search task) by signal.

Table 7. Errors associated with tactile signals.

Course	Correct Signal	Reported Signal
IMT Walking	Danger	Rally (2) double-time (1)
	Double-time	Danger (2)
	Freeze	Rally (1)
	Rally	Danger (1)
IMT Obstacles	Danger	Double-time (1) rally (1) freeze (1)
	Double-time	Freeze (2) rally (1) danger (2) halt (1)
	Freeze	Double-time (1) danger (2)
	Rally	Freeze (3) halt (1) danger (1)
Tactical Movement	Danger	No response (1) double-time (1) freeze (3) halt (1)
	Double-time	Freeze (1) rally (1)
	Freeze	—
	Rally	Danger (2)

Number of flags detected. Soldiers detected an average of 10.61 flags with the glove/tactile system (standard deviation = 2.70) and 9.71 flags with the hand-arm signals (standard deviation = 2.77). While the mean number was higher with the glove system, the difference did not meet significance criteria, though it did come close (F 1, 30 = 3.64, p = 0.07, $\eta\rho^2 = 0.11$). There was considerable variance among the Soldiers with regard to this performance. Results are shown in figure 37.

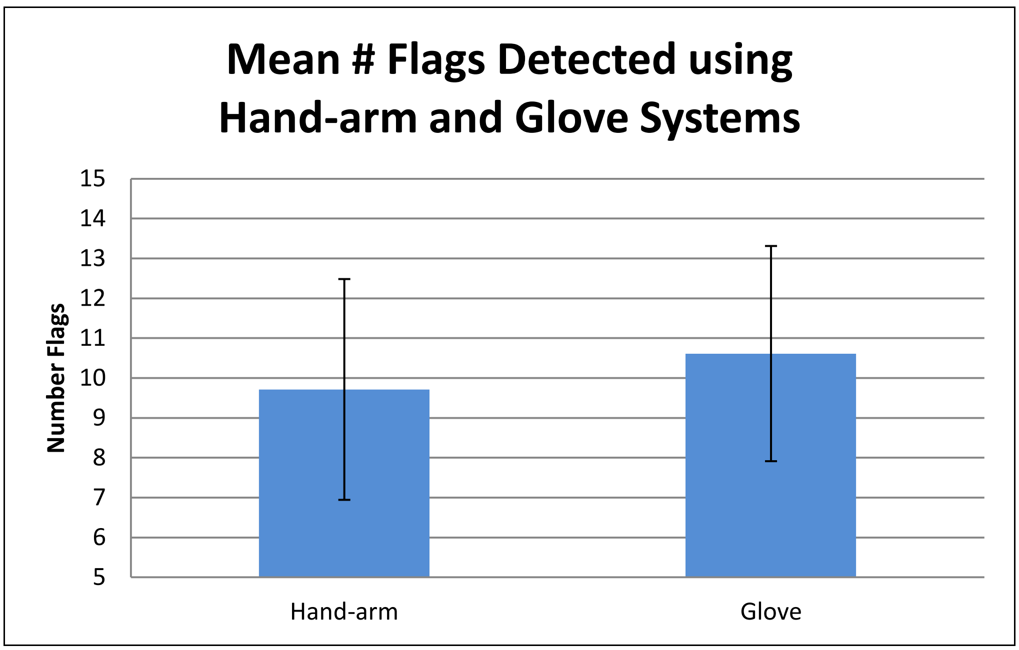

Figure 37. Mean number of flags detected using the hand-arm and the glove/tactile systems.

5.1.5 Perceptions of Workload and Self-Efficacy

Soldiers provided self-report ratings of workload and self efficacy for using the glove for sending signals and using the tactile vest to receive signals. Table 8 and figure 38 provide mean direct ratings for NASA-TLX workload factors (i.e., mental, physical, time pressure, effort, frustration), including one factor that represents perception of how well they performed (i.e., performance). Each scale ranged from 1 (extremely low) to 10 (extremely high). Ratings of workload were relatively low for both components, while ratings of performance were relatively high. Direct ratings were used as they have been demonstrated valid when compared to weighted ratings (Hart and Staveland, 1988; Hart, 2006). Soldiers tended to report confusion with the weighted process, which also confounded measures of workload with a measure of self efficacy (i.e., performance scale). For this reason, we kept these constructs separate.

Table 8. Mean NASA TLX ratings for glove and tactile vest.

System Component	TLX Mental	TLX Physical	TLX Time Pressure	TLX Effort	TLX Frustration	TLX Performance
Glove	2.71 (1.88)	1.79 (1.13)	2.00 (1.15)	2.14 (1.48)	2.68 (1.83)	7.32 (2.03)
Tactile Vest	3.40 (2.19)	2.23 (1.67)	2.70 (1.72)	2.93 (1.84)	2.63 (2.18)	7.83 (2.38)

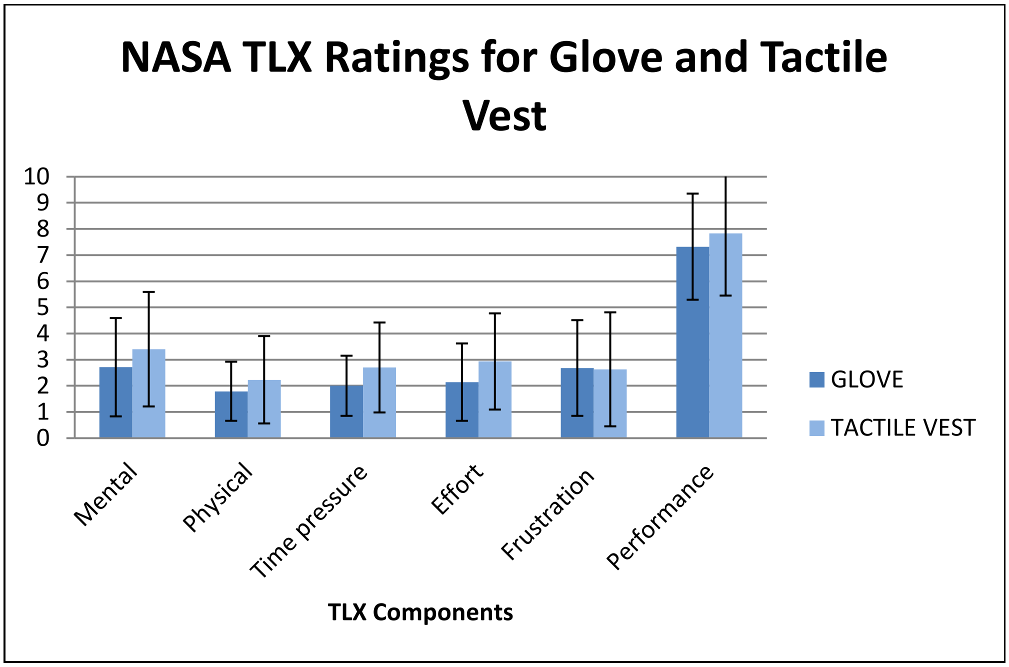

Figure 38. Mean NASA TLX ratings for glove and tactile vest.

5.1.6 Soldier Feedback

5.1.6.1 Glove Component

Comfort and usability. Soldiers were generally positive about the comfort of the glove. The glove received a mean rating of 5.50 (7-pt scale; between positive and very positive) for comfort. Simultaneously, many suggestions were offered as improvements, many of which had to do with improving form and fit through having a range of different sizes, with different fit between women and men. Other suggestions were to reduce the bulk, increase elasticity, and make the sensors interchangeable with different types of gloves.

Effectiveness. The gloves had problems with two of the four signals and this was reflected in feedback. Soldiers generally assigned high ratings for three signals, using a 7-pt scale from extremely negative to extremely positive (i.e., freeze [6.0], double-time [5.11], and rally [5.67]) and lower ratings for “danger area” (2.85). Soldiers commented on the need for greater reliability, accuracy, and more robust gestures that do not require a high degree of precision to execute. Soldiers also pointed out the need to make the system wireless.

Responses to 7-pt agree-disagree Likert scales were generally positive and key responses are provided in table 9. There was complete agreement that the glove was easy to learn and easy to use. Soldiers also agreed that the glove was a good concept for Soldier operations, and allowed more attention to be spent on surroundings. When asked about the type of situations where the glove concept could be useful, assuming combat-readiness, Soldiers emphasized covert operations that require silence, whether for dismounted patrol or reconnaissance. They also mentioned situations where a larger number of Soldiers split up into squads that are out of line of sight, when they have to coordinate on the fly. Night operations were also listed and any situations where visibility is impaired. The mean overall rating for operational relevance for Soldier missions was 5.91 on a 7-pt scale, where 6.00 is “very likely.”

They also indicated a need for further improvement in signal cueing, probably due to problems with one of the cues (i.e., danger area).

Table 9. Degree of agreement with statements regarding the glove as used for communication (7-pt Likert scale).

Rated Comments Regarding Glove System for Communication	Mean
a. “It was easy to learn the glove commands for hand arm signals.”	6.20
b. “It was easy to execute the glove commands.”	6.97
c. “The glove is a good concept for hand-arm communications.”	5.63
d. “The glove helped keep my attention on my surroundings.”	5.40
e. “The glove sent the signal easily the first time.”	4.17
f. “I prefer to use regular arm and hand signals.”	3.77
g. “The glove is preferable to regular arm and hand signals for some situations.”	5.30
h. “The glove concept has a lot of potential for operational usefulness.”	5.83

5.1.6.2 Tactile Harness Component

Comfort and usability. Soldier assessments of the comfort of the tactile harness were fairly high, with a mean of 5.17 on a 7-pt scale (5 = positive) for comfort and 4.77 for adjustability. Soldiers provided many remarks and suggestions, which are provided in the discussion section.

Effectiveness. Soldiers rated the ease by which they recognized each tactile signal. Ratings indicated that Soldiers found the signals to be easy to recognize. Mean ratings, based on a 7-pt scale, ranged from 5.15 for “danger area” to 6.30 for “rally.” Soldiers provided remarks and suggestions, which are provided in the discussion section.

The tactile signals were rated as a bit noisy. The mean rating was 3.73 on a 7-pt scale ranging from 1 = extremely noisy to 7 = silent. While the system was described as useful in operations, the noise level was considered too high for stealth operations, such as reconnaissance, capture mission, raid, or ambush. Some Soldiers stated they had a hard time feeling the signals, particularly during strenuous movement, and that the signals should be adjustable for power and noise.

Table 10 provides mean ratings describing the extent to which Soldiers agreed to statements (1 = strongly disagree to 7 = strongly agree). Soldiers had a high degree of agreement with positive statements, with the highest rating for “the tactile cues help me keep my attention on my surroundings.” Ratings reflected disagreement to negative statements, such as “the tactile signal was annoying.”

Table 10. Degree of agreement with statements regarding the tactile vest as used for communication (7-pt Likert scale)

Statements Regarding Tactile Harness	Mean
Postive Statements	
"The tactile cues help keep my attention on my surroundings."	6.33
"The tactile cues can be a useful way for Soldiers to communicate."	6.23
"It was easy to feel each tactile signal while walking."	6.20
"It was easy to feel each tactile signal in general."	6.10
"The tactile cues are a good means of silent communication."	6.17
"The tactile cues are a good substitute when radios cannot be used."	6.17
"I would like the ability to create my own commands that could be used with this tactile system (e.g., create commands based on unit SOPs)."	5.73
"A moving tactile pattern should indicate an action cue (e.g., get down, move out)."	5.67
"It was easy to feel each tactile signal while performing IMT maneuvers."	5.27
"I was very certain what each signal meant."	5.00
"It was easy to understand what each signal meant."	4.73
"I recognized each signal immediately."	4.87
Negative Statements	
"The tactile signal felt ticklish."	1.83
"The tactile signal was annoying."	2.33
"The tactile cues are too noisy for regular patrols."	2.73
"The tactile signal should be stronger."	3.17
"The tactile cues are too noisy for covert missions."	4.50

<u>Operational relevance.</u> Soldiers were asked to assess the potential usefulness of the tactile harness concept for Army operations, on a scale ranging from 1 = extremely ineffective to 7 = extremely useful. Ratings were high for night patrol/overwatch (mean = 6.07). Many suggestions were made with regard to who should have the system; most agree that it should go to the SL and PLs, and sometimes to the TLs (team leaders). Situations where the tactile cues were considered useful included patrol, overwatch, general infantry missions, road marches, remote communication with drones, and situations when/where visibility is degraded. Some suggestions for other useful commands included IED (i.e., improvised explosive device) (found), halt, linear danger area, get down, stand up, contact left/right, fire, cease fire, (I) hear something, (I) see something, all secure, on the way back, sound alarm, wedge, file, column, and staggered. Soldiers rated the relevance for EOD missions somewhat lower (mean = 4.41) but still useful. The concept of usefulness to EOD related to the communication from and to the EOD technician who is disarming the explosive and to warn of danger ahead. Some suggestions for tactile signals included abort, left-blue versus right-red, all clear, look around, cut the wire, and fall back. Several suggested a preference for tailoring their own cues to a mission, with regard to the tactile pattern and meaning. This was also reflected in a mean rating of 5.73 regarding a preference to make their own signals (see table 10).

5.2 Robot Control: OCU and Glove-Based Control

5.2.1 Performance Measures

Table 11 provides mean and standard deviations for time to complete task (in seconds), number of minor errors, and number of major errors. The difference in time taken to complete the task was not significant ($F_{1, 27} = 1.39$, $p = 0.25$, $\eta\rho^2 = 0.05$), perhaps due to the high variance around OCU time (SD = 19.30 for OCU versus 7.82 for glove control, see figure 39). The difference in minor errors was also not significant ($F_{1, 27} = 2.49$, $p = 0.13$, $\eta\rho^2 = 0.08$. However, the number of major errors by the glove system was significantly higher ($F_{1, 27} = 6.31$, $p = 0.02$, $\eta\rho^2 = 0.19$) (figure 40).

Table 11. Means and standard deviations for OCU vs. glove-based robot control overall tasks.

OCU			Glove		
Time (s)	Minor Error	Major Error	Time (s)	Minor Error	Major Error
24.42 (19.30)	0.5 (0.37)	0.22 (0.26)	28.86 (7.82)	0.66 (0.41)	0.36 (0.36)

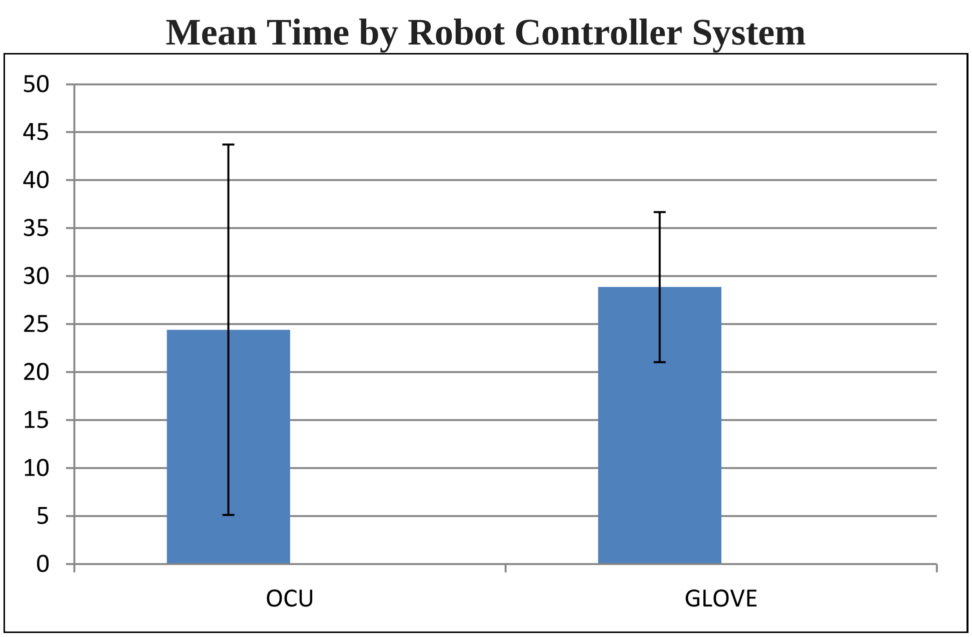

Figure 39. Mean time (seconds) by Robot Controller System.

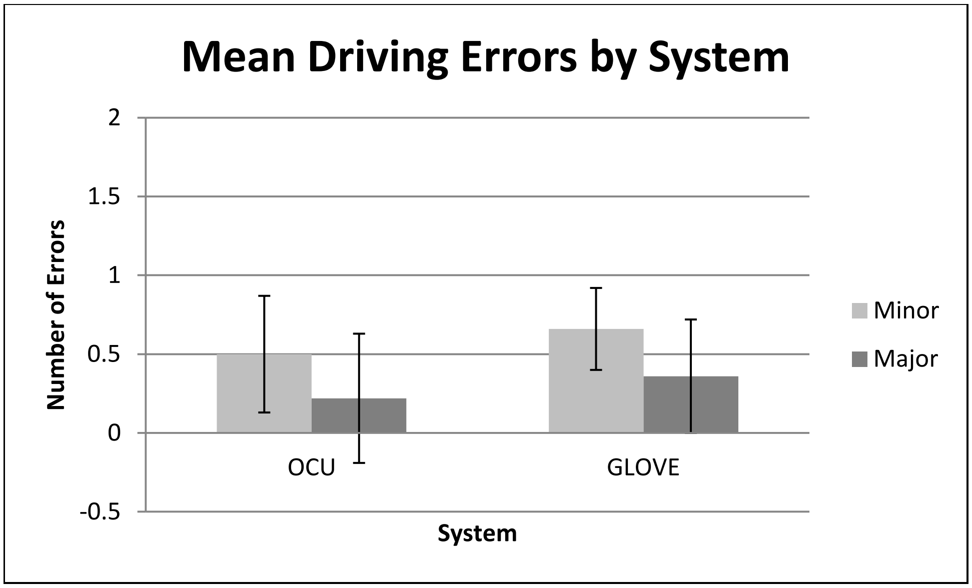

Figure 40. Mean driving errors by the OCU and glove-based systems.

Driving error: Fine control stop. At one station, the robot had to be guided toward a post to get as close to it as possible without hitting it, forward and backward. Differences between the glove and the OCU were not significant for forward movement ($F_{1, 25} = 0.08$, $p = 0.77$, $\eta\rho^2 = 0.00$) or for backing
($F_{1, 24} = 0.00$, $p = 1.00$, $\eta\rho^2 = 0.00$). Table 12 provides the descriptive data (i.e., means, standard deviations).

Table 12. Mean percentages (and standard deviations) for robot hitting the post during forward and backward movement.

System	% Hit Post Forward (Std. Dev.)	% Hit Post Backward (Std. Dev.)
Glove	0.28 (0.46)	0.35 (0.49)
OCU	0.32 (0.47)	0.30 (0.46)

If the robot did not hit the post, the distance of the robot from the post was measured. The goal was to get as close as possible without hitting the post. Table 13 and figure 41 provide the descriptive data (i.e., means, standard deviations). Differences were not significant for forward movement ($F_{1, 11} = 0.75$, $p = 0.40$, $\eta\rho^2 = 0.06$) but were significant for backward movement ($F_{1, 11} = 5.49$, $p = 0.04$, $\eta\rho^2 = 0.33$).

Table 13. Mean distance (inches) from post during forward and backward movement.

System	Mean Distance Forward (Std. Dev.)	Mean Distance Backward (Std. Dev.)
Glove	2.73 (1.54)	4.13 (2.52)
OCU	2.21 (1.80)	2.90 (2.72)

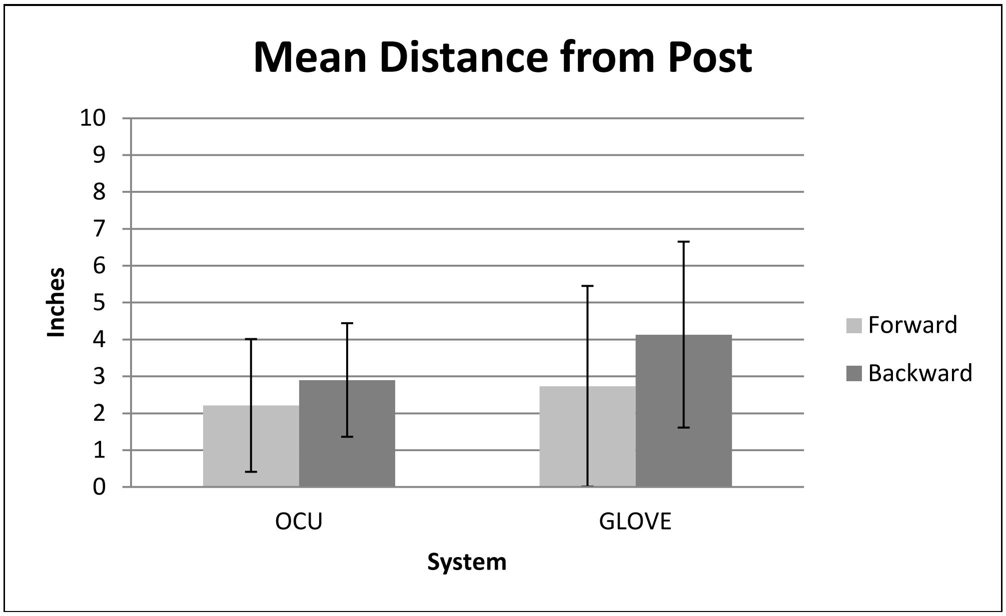

Figure 41. Mean distance from post by OCU and glove controller systems during forward and backward movements.

Breakdown of Robot Controller performance by system and task. Table 14 provides the mean time, mean number of minor errors, and mean number of major errors, by each task performed by the Soldier.

Table 14. Mean robot control performance measures by system.

System	Mean Time						
	Narrow Forward	Narrow Backward	ZigZag	Figure 8 Forward	Figure 8 Backward	Station Forward	Station Backward
OCU	26.64 (9.55)	30.21 (11.34)	16.39 (7.53)	22.89 (9.50)	21.11 (8.32)	12.07 (3.76)	16.54 (8.02)
Glove	42.73 (16.62)	36.33 (13.60)	23.27 (11.09)	30.52 (12.65)	27.48 (11.04)	17.66 (7.47)	18.34 (8.85)
	Minor Errors						
OCU	0.57 (0.74)	0.54 (0.69)	1.29 (1.12)	0.68 (0.77)	0.43 (0.69)	0.00 (0.00)	0.00 (0.00)
Glove	0.57 (0.86)	0.83 (0.79)	1.30 (1.21)	0.90 (1.14)	0.83 (0.81)	0.00 (0.00)	0.00 (0.00)
	Major Errors						
OCU	0.11 (0.42)	0.50 (0.92)	0.39 (0.68)	0.14 (0.36)	0.39 (0.74)	0.00 (0.00)	0.00 (0.00)
Glove	0.30 (0.70)	0.57 (0.86)	0.50 (0.97)	0.41 (0.63)	0.66 (0.97)	0.00 (0.00)	0.00 (0.00)

5.2.2 Perceptions of Workload and Performance

Mean values and standard deviations for NASA TLX constructs are provided in table 15 and figure 42. Overall, values were higher for the glove controller with regard to workload. These differences were significant for mental workload (F 1, 27 = 16.98, $p = 0.00$, $\eta\rho^2 = 0.39$), physical workload (F 1, 27 = 7.90, $p = 0.01$, $\eta\rho^2 = 0.23$), time pressure (F 1, 27 = 6.82, $p = 0.01$, $\eta\rho^2 = 0.20$), effort (F 1, 27 = 15.43, $p = 0.00$, $\eta\rho^2 = 0.36$), and frustration (F 1, 27 = 16.43, $p = 0.00$, $\eta\rho^2 = 0.38$). Self-ratings of how well each Soldier thought they performed were also significantly different (F 1, 27 = 8.79, $p = 0.01$, $\eta\rho^2 = 0.25$).

Table 15. Mean values and standard deviations for TLX rating scales.

System	TLX Mental	TLX Physical	TLX Time Pressure	TLX Effort	TLX Frustration	TLX Performance
Glove	4.55 (2.39)	2.55 (1.69)	3.32 (1.78)	4.19 (2.30)	3.81 (2.43)	6.71 (2.68)
OCU	2.86 (2.05)	1.75 (1.38)	2.46 (1.62)	2.39 (1.52)	2.21 (1.77)	8.11 (2.71)

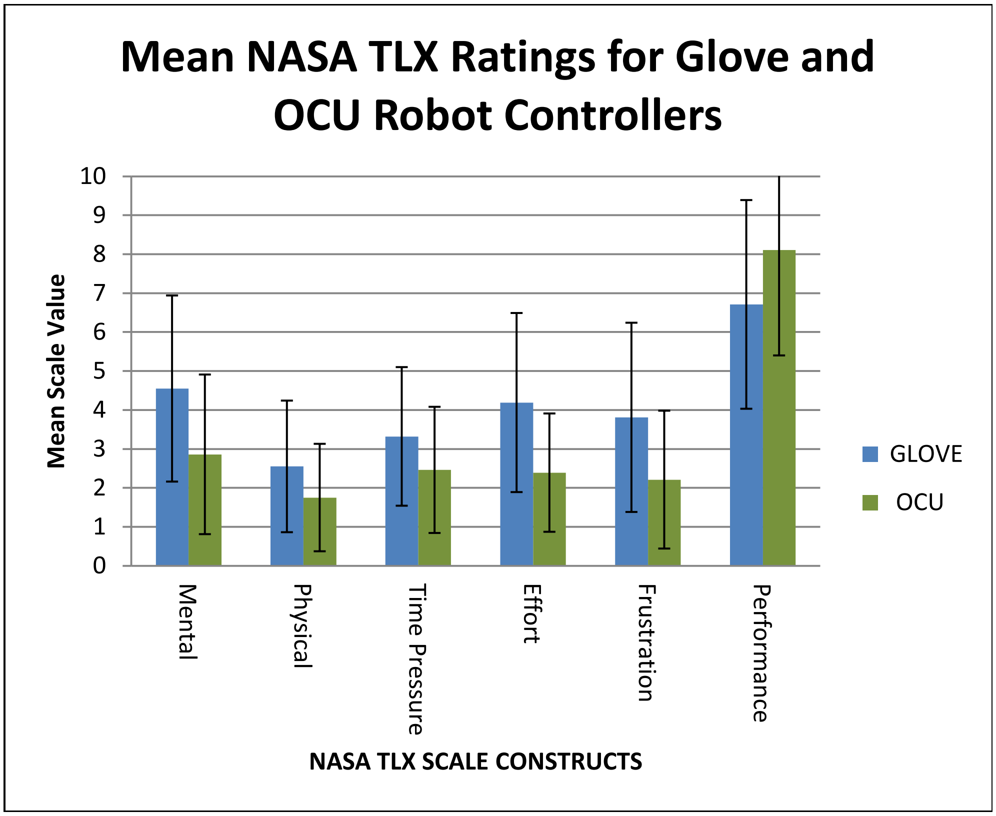

Figure 42. Mean ratings for NASA TLX constructs for glove and OCU controllers.

5.2.3 Spatial Ability: Robot Control

Spatial ability scores did not correlate significantly with any robot controller performance measure. Spatial ability scores were also analyzed as a covariate in analyses regarding robot controller performance. The factor was not significant for most of the criterion performance values; however, it approached significance for forward movement distance. Table 16 provides a breakdown of performance scores for robot controller by Soldiers scoring in the lower versus upper half of spatial performance scores.

Table 16. Mean performance scores for glove vs. OCU controllers, by lower vs. higher spa scores.

Glove	Time	Minor	Major	Forward Distance	Forward Hit Post	Backward Distance	Backward Hit Post
Glove Lower Spa	28.71	0.59	0.41	2.85	0.29	4.33	0.36
Glove Higher Spa	29.01	0.73	0.31	2.62	0.29	3.94	0.36
OCU Lower Spa	26.80	0.40	0.26	2.20	0.27	2.50	0.27
OCU Higher Spa	21.67	0.62	0.17	2.22	0.38	3.38	0.33

5.2.4 Soldier Feedback

Comfort and usability. The glove used for robot control was rated highly by Soldiers for comfort (mean = 6.21, 7-pt scale). Several also commented on the comfort and fit of the glove. Suggestions for further improvement included making it lighter, in different sizes, and with a more breathable material to minimize sweat. Also, there should be a "pause" button so that one can relax the hand. Certain gestural positions were fatiguing over time. Operators were not certain of the range for control, as there is no cue that the robot is out of range, except for nonresponsiveness.

Table 17 provides mean ratings of comfort and ease of use for each gestural command. Ratings were positive for ease of use in general (mean = 4.90 where 5.0 = positive) and for each command, with higher ratings for the commands "move forward" and "move back." However, the gestures were thought to be fatiguing if sustained, and whole-hand movements may be less taxing. Some commented that the glove controller was too sensitive, while others thought the control as resulting in jerky movements, which may be an attribute of the robot. This was stated as being more problematic if the operator is also walking. Several Soldiers commented that their performance was limited due to the robot not being able to move forward and turn at the same time; that is, they had to stop and turn in place. Overall, the robot controller/robot system needs improvements to result in smooth and precise control. In addition, it was suggested that the glove have an "activate" switch, and that the robot possess capabilities similar to those of other Army robots, particularly that of having a camera-based view.

Table 17. Mean ratings for glove-based robot control.

Mean Ratings Regarding Glove for Robot Control	Mean
Comfort of glove	6.21
Ease of controlling the robot using the glove in general	4.90
Ease of controlling the robot using the glove: MOVE FORWARD	5.67
Ease of controlling the robot using the glove: MOVE BACKWARD	5.63
Ease of controlling the robot using the glove: STOP	4.20
Ease of controlling the robot using the glove: LEFT TURN	4.73
Ease of controlling the robot using the glove: RIGHT TURN	4.63
Narrow gap: guiding the robot through a gap in engineering tape	5.07
Zigzag: guiding the robot through a zigzag course	4.47
Figure 8: guiding the robot around wooden logs	4.77
Stationary object: guiding the robot to a stationary object, then backing to another point	4.87

Table 18 provides mean ratings in response to 7-pt agree-disagree (Likert) scale. The glove was rated very easy to learn, and to use, though somewhat time consuming. In general ratings were positive with regard to robot response and operational relevance. On a separate scale of potential usefulness (1 = extremely unlikely to 7 = extremely likely), the mean rating was 5.60 (likely – very likely), also indicating that Soldiers thought highly of the concept of glove-based control, assuming certain improvements were attained.

Table 18. Mean Likert ratings regarding glove-based robot control.

Statements Regarding Glove-Based Robot Control	Mean
“It was easy to learn the glove commands for robot control.”	6.30
“It was easy to execute the glove commands.”	5.50
“The robot responded effectively to commands.”	4.63
“The glove is a good concept for robot control.”	5.40
“The glove helped keep my attention on my surroundings.”	4.03
“It was too time consuming to maneuver the robot through the obstacles.”	4.90

Soldiers described several advantages of the glove-based controller. It was considered lightweight, small, compact, easy to control and operate the robot, and it leaves a free hand to carry a weapon. They listed several situations where the system would be useful, such as reconnaissance, searching for IEDs, building clearing, and EOD operations, particularly if integrated with a camera and a gripper capability.

At the same time, many issues were raised for improvement. Several Soldiers commented they felt they could improve their performance with more practice, but that with the initial use, the movements were too sensitive and jerky. Some commands were sluggish or unresponsive to the gesture, and some gestures were described as fatiguing. Several improvements were suggested for the robot itself. EOD Soldiers were particularly emphatic about the need for a robot with camera and gripper capabilities.

6. Discussion/Conclusion

6.1 Glove/Tactile System for Covert Communications

Use of the instrumented glove with a tactile display resulted in a significantly higher average percentage of detections (100%), when compared to traditional hand and arm signals (84%–88%). The glove-based signals were also detected significantly faster. This was not unexpected, as the traditional hand and arm signals were presented from behind such that detection was dependent on the Soldier's ability to periodically look at other team members while also maneuvering through the woods and visually monitoring his surroundings. This is a common situation when the platoon leader or point person is placed between two squads in formation. The differences between glove-based signals and hand and arm signals were more pronounced during tactical movement and IMT obstacles, compared with signals presented during walking. Soldiers were also able to correctly interpret the tactile signals as accurately as they interpreted the hand and arm signals (87%–95%, across task conditions). Data also suggested that Soldiers were able to pay more attention to their surroundings when using the glove and tactile vest system. Soldier ratings of cognitive workload associated with the glove/tactile vest were relatively low, ranging from 1.79 to 3.40 on a 10-pt scale.

Given the high percentage of glove-based signals that were detected, operator interpretation of the signals, we can assume the signal strength was sufficient for perception. Interpretation is also dependent on other characteristics of the tactile patterns regarding tactile salience (Hancock et al., in press; Mortimer et al., 2011). Operator accuracy of tactile signal interpretation was high; however, it should be noted there were only two to four signals that were used. Of the four signals, two were associated with higher accuracy. It should be noted this is a preliminary evaluation for the purpose of informing development of the system during the course of the funded project. Further research is suggested with regard to the characteristics of tactile patterns that would make the signals more easily and correctly interpreted. In addition, more research is indicated with regard to the number of tactile signals that can be easily trained and discriminated. Improved sensor technology in the next generation glove will alleviate many of the gesture recognition issues.

While performance-based results demonstrated a proof of concept of glove-based covert signaling, they also demonstrated some limitations. Some of the glove-based cues did not function properly, such that some Soldier experienced only two or three of four signals. Further improvements are needed to extend and refine capabilities to provide a greater range of signals with more reliable signaling. In addition, some Soldiers experienced difficulty performing particular gesture(s). The gestures need to be further refined for ease of execution.

As stated previously in the results section, Soldier feedback for the glove and tactile vest for covert communications, as a proof of concept, was overall favorable. Soldiers agreed that the glove was easy to learn, easy to use, and is a good concept for Soldier operations because it allowed more attention to be spent on surroundings. When asked the type of situations where the glove concept could be useful, assuming combat-readiness, Soldiers emphasized covert operations that require silence. They also mentioned situations where a larger number of Soldiers split up into squads that are out of line of sight, when they have to coordinate on the fly. Night operations were also listed, and any situations where visibility is impaired.

Soldier ratings of the comfort of the tactile harness were fairly high for comfort and for adjustability. However, some Soldiers found the system to be too large and needed better adjustments and weight distribution. The system as a whole, including the pack, was considered to be bulky and heavy, and several Soldiers commented on the need to reduce battery weight and size. Several suggested the attachments be of a different design from the hook and loop fasteners, which were described as somewhat weak. Pouches were described as moving around, and the wires sometimes impeded movement during IMT. One Soldier stated that the controller fell out of the pouch and would not fit properly. Several commented on compatibility with body armor. In addition, after several sessions with the tactile harness, issues were raised as to how the system can be kept clean.

Soldier ratings indicated that they found the tactile signals to be easy to recognize. They also stated the signals were easy to learn and remember. Suggestions included using other locations on the torso for tactile cues, such as the back or stomach. It was suggested that “Danger area” should vibrate from the back to the front, rather than front to back. Several commented that “Danger area” was not working.

The tactile signals were rated as a bit noisy. While the system was described as useful in operations, the noise level was considered too high for stealth operations. Some soldiers stated they had a hard time feeling the signals, particularly during strenuous movement, and that the signals should be adjustable for power and noise. Similar feedback was documented during a previous limited field experiment during the Crimson Viper U.S. Navy exercise (Vice, 2013). A possible solution is to adjust tactor intensity (and thus noise) based on the speed of movement. For example, a slow moving night patrol would have lower tactor noise then a faster moving day movement.

Soldiers also rated the potential usefulness of the tactile harness concept for Army operations and agreed it was very useful. Many suggestions were made with regard to who should have the system; most agree that it should go to the SL and PLs, and sometimes to the TLs. Situations where the tactile cues were considered useful included patrol, overwatch, general infantry missions, road marches, remote communication with drones, and situations when/where visibility is degraded. Some suggestions for other useful commands included IED (found), halt, linear danger area, get down, stand up, contact left/right, fire, cease fire, (I) hear something, (I)

see something, all secure, on the way back, sound alarm, wedge, file, column, and staggered. Soldiers rated the relevance for EOD missions somewhat lower (mean = 4.41), but still useful. The concept of usefulness to EOD related to the communication from and to the EOD technician who is disarming the explosive, and to warn of danger ahead. Some suggestions for tactile signals included abort, left-blue vs. right-red, all clear, look around, cut the wire, and fall back. Several suggested a preference for tailoring their own cues to a mission, with regard to the tactile pattern and meaning.

To summarize, outcomes associated with the integration of instrumented glove and tactile vest for covert communications were generally positive. Use was associated with more effective communications that were more quickly and accurately understood. Soldiers rated the comfort and operational relevance of the system highly and provided detailed feedback with regard to improvements. Thus the proof of concept was very favorable; however, many improvements with regard to signal reliability, diversity, and strength are indicated.

6.2 Gesture-Based Robot Control

Soldiers performed several different maneuver tasks using the glove and a traditional handheld robot controller. The task demands were designed to be difficult and challenging. While the handheld controller was associated with lower average number of driving errors, the overall concept of glove-based robot control was demonstrated as effective. Though the handheld controller and the glove controller were associated with similar times to perform the robot maneuver tasks, the handheld controller was associated with a much greater variability in times; that is, some Soldier s were much faster while others were much slower. In contrast, the glove controller was associated with less variance in timed performance, even after a very short training session. This may reflect differences in Soldier experience with handheld controllers. It may be that the glove-based approach is more easily learned by novice operators. This would suggest further investigation with regard to training content, training time, and individual differences.

Soldier perceptions of NASA TLX workload were higher using the glove than the handheld controller. These differences were significant for mental, physical, time pressure, effort, and frustration. Self-ratings of how well each Soldier thought they performed were also significantly different, with higher ratings for the handheld OCU.

Measures of spatial ability showed a familiar pattern for the handheld controller. Soldiers with higher spatial ability were associated with somewhat faster times. In contrast, spatial ability was not associated with different performance times for the glove condition. This suggests that the glove-based approach may be less difficult overall, with regard to spatial skill demand, particularly when one controls for experience with robot controllers. These results also suggest a need for further investigation with regard to training content, training time, and individual differences.

The glove used for robot control was rated highly by Soldiers for comfort (mean = 6.21, 7-pt scale). Several commented on the comfort and fit of the glove. Additional suggestions included sizing considerations for a larger range, particularly for smaller females; an off/on/pause function, and an out of range monitor/alert. Several improvements were suggested for the robot itself. EOD Soldiers were particularly emphatic about the need for a robot with camera and gripper capabilities.

To summarize, this preliminary assessment showed the instrumented glove received very favorable feedback from Soldiers as being operationally relevant and worth pursuing. The glove did not out-perform the handheld controller; however, it should be noted that the task maneuvers were very complex and challenging, with tight turns and small spaces. Outcome variability also indicated that performance with the glove may become more effective over time, with more training and practice. Soldiers provided a variety of suggestions to improve the system, as it becomes more fully developed.

6.3 Future Efforts

Findings from this report will serve to inform further development of gesture-based controls. ATinc is currently developing a next generation user-interface glove (NuGlove) that uses a combination of gyroscopes, accelerometers, and a digital compass embedded into the fingers, back of the hand, and wrist of a tactical field glove, providing finger and hand motion tracking in addition to absolute magnetic azimuth orientation. Advanced concepts include the ability to provide directional information utilizing the embedded compass. Additionally, the IMU-Glove can be used for proportional inputs similar to a joystick, which can be used to drive a robotic asset or a graphical user interface input. This advanced concept system is being designed in multiple sizes and will take advantage of new antibacterial fabrics to allow for expended use without cleaning. Future efforts with regard to covert communications should address issues regarding fit, comfort, ease of use, additional gestural-based cueing, and more precise control. For robot control, promising avenues of research include the development of pointing gestures and the integration with speech commands. The addition of a dual glove control methodology will increase performance in future experiments. For example, during simple robotic tasks, single glove control with “weapon at the ready” can be used. To control high degree-of-freedom payloads such as EOD manipulator arms, the operator can then switch to dual glove control. This control method has been demonstrated in the lab for an 8 degree-of-freedom manipulator arm. Future research should also investigate robot telemetry feedback to the haptic vest during operation. For example, this would allow the operator to “feel” arm joint angular velocities or forces being applied by the gripper, which has been shown to increase performance during highly dexterous EOD type manipulator arm tasks.

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Appendix A. Informed Consent Form

This appendix appears in its original form, without editorial change.

Informed Consent Form

Army Research Laboratory, Human Research & Engineering Directorate, Aberdeen Proving Ground, MD

Title of Project: Utilizing Glove-based Gestures and a Tactile Vest Display For Covert Communications and Robot Control

Project Number: ARL-
Sponsor: Army Research Laboratory
Principal Investigators:
Name: Linda R. Elliott
Division: Human Factors Integration Division
Branch: Weapons branch
Team: Field Element at Maneuver Center of Excellence, Fort Benning, GA.
Phone Number: 706 545 9145
Email: Linda.r.elliott.civ@mail.mil
Name: Anna Skinner
Organization: AnthroTronix, Inc.
Phone Number: 301-495-0770 x109
Email: askinner@atinc.com

You are being asked to join a user evaluation. This consent form explains the user evaluation and your part in it. Please read this form carefully before you decide to take part. You can take as much time as you need. Please ask the research staff any questions at any time about anything you do not understand. You are a volunteer. If you join the study, you can change your mind later. You can decide not to take part now or you can quit at any time later on.

Purpose of the Evaluation

The purpose of this user evaluation is to introduce new technology that uses vibration-based signals for Soldier communication and orientation. You will be introduced to equipment concepts and capabilities, trained on operation, and requested to interact with the system. Afterward, you will be asked for your opinions with regard to operational relevance and user requirements. You will be asked to review the system, participate in experiment sessions where you may use an instrumented glove, experience haptic pattern sensations similar to cell phone vibrations from a belt, and use a GPS-enabled handheld computer. You will then provide feedback on the system components.

Procedures to be Followed

Prior to beginning the study, you will fill out a demographics questionnaire (appendix B). You will be briefed on the purpose and procedures of the study. During the demonstration of the equipment, you may be asked to don a belt containing 8 tactors that, when activated, will provide vibrations like those emitted from a cell phone. You may also be asked to wear a glove with embedded sensors to record your hand movements and gestures; this glove may be used to drive a robot. You may also be asked to use a GPS-enabled handheld computer for communication and navigation tasks.

After interacting with the system, you will be asked to complete a questionnaire and participate in discussion of the equipment.

Discomforts and Risks

The risks associated with this experiment are considered minimal. The risks that will be encountered during this investigation are typical of the risks encountered when training and performing indoor duties in non-combat routines. You may be requested to walk outdoors in a parking lot and open field environment. Please inform investigators if you experience any discomfort or problems during the investigation. In the unlikely event of an injury, a range radio or cell phone will be used to call the '911' on-post emergency medical personnel.

Benefits

There are no personal benefits for you for taking part in this study. However, your participation will provide valuable information about Soldier performance that will assist in the design of future Army systems.

Duration

It will take approximately two to three hours for you to take part in this study.

Confidentiality

Your participation in this research is confidential. The data will be stored and secured at Aberdeen Proving Ground, in a locked file cabinet. The data, without any identifying information, will be transferred to a password-protected computer for data analysis. After the data is put in the computer file, the paper copies of the data will be shredded. This consent form will be sent to Army Research Laboratory's Institution Review board, where it will be retained for a minimum of three years.

If the results of the experiment are published or presented to anyone, no personally identifiable information will be shared. Publication of the results of this study in a journal or technical report, or presentation at a meeting, will not reveal personally identifiable information. The research staff will protect you data from disclosure to people not connected with the study. However, complete confidentiality cannot be guaranteed because officials of the U. S. Army human Research Protections Office and the Army Research Laboratory's Institutional Review board are permitted by law to inspect the records obtained in this study to insure compliance with laws and regulations covering experiments using human subjects.

We would like your permission to take pictures during the experimental session. The pictures will be printed in technical reports and shown during presentations when we describe the results of the study. To protect your identity, we will pixelate the image to obscure your face. You can still be in the study if you prefer not to be photographed. Please indicate below if you will agree to allow us to take pictures of you.

I give consent to be photographed or videotaped during this study: ____Yes ____No
Please initial: ____

Contact Information for Additional Questions

You have the right to obtain answers to any questions you might have about this research both while you take part in the study and after you leave the research site. Please contact anyone listed at the top of the first page of this consent form for more information about this study. You may also contact the chairperson of the human Research & Engineering directorate, Institution Review board, at (410) b78-d99b with questions, complaints, or concerns about this research, or if you feel this study has harmed you. The chairperson can also answer questions about your rights as a research participant. You may also call the chairperson's number if you cannot reach the research team or wish to talk to someone else.

Voluntary Participation

Your decision to be in this research is voluntary. You can stop at any time. You do not have to answer any questions you do not want to answer. Refusal to take part in or withdrawing from this study will involve no penalty or loss of benefits you would receive by staying in it.

Military personnel cannot be punished under the Uniform code of Military Justice for choosing not to take part in or withdrawing from this study, and cannot receive administrative sanctions for choosing not to participate.

Civilian employees or contractors cannot receive administrative sanctions for choosing not to participate in or withdrawing from this study.

You must be 18 years of age or older to take part in this research study. If you agree to take part in this research study based on the information outlined above, please sign your name and the date below.

You will be given a copy of this consent form for your records.

Do not sign after the expiration date of May 2014.

____________________________________ ____________________

Participant Signature date

____________________________________ ____________________

Person Obtaining consent date

Appendix B. Demographic/NASA TLX Questionnaires

This appendix appears in its original form, without editorial change.

Demographics Questionnaire

(extra blank spaces removed)

Date: ________________Participant ID (ROSTER): _________

1. General Information

a. Age (yrs): _____ b. Gender: M F c. Handedness: L R

d. Height (in): ______

e. Do you have any of the following (Circle all that applies):

Astigmatism Near-sightedness Far-sightedness

Other (explain):____

f. Do you have corrected vision (Circle one)? None Glasses Contact Lenses

If so, do they correct for items listed in e. above (Circle one): Yes No

g. Do you have any hearing loss or other impairments? If so, please explain.

____

h. Do you currently have any skin sensitivities on your torso (chest, waist) that might be irritated by wearing a haptic belt (for example, poison ivy, insect bites, rash, etc.)?

____

i. On a scale from 1 to 5, how ticklish are you? (chest/waist area)

1 = Not at all_________2____________3___________4__________5 = Very ticklish

2. Military Experience

a. How many years have you been in the military? ________ Current rank ____________

b. What is your MOS? ________________

c. Please list all combat deployments (Iraq, Afghanistan, etc.) and the length (Years / Months) of each.

Location Time

_____________________________________ _______________________

d. Do you have operational experience in complex urban terrain? ___Yes ___No

If yes, where ____

e. Do you have any experience with scanning tasks (e.g., searching for targets)? ____Yes ___No

If yes, please explain (dismounted infantry) (mounted-vehicle)

____

f. Have you ever conducted security patrols in complex urban terrain? ___Yes ___No

If yes, where ____

g. Have you ever used camera systems to conduct local security? ___Yes ___No

If yes, which systems ____

h. Have you any experience with military robots? If so, what type and purpose?

Type Purpose

__________________ ____

3. Educational Data

a. What is your highest level of education received? Select one.

____ GED
____ High School
____ Some College
____ Bachelors Degree
____ M.S/M.A
____ Ph.D.
Other: _______________________

b. If applicable, what subject is your degree in (for example, Criminal justice)?
____

4. Computer Experience

a. How long have you been using a computer?

__Less than 1 year ___ 1-3 years ___4-6 years ___7-10 years ___10 years or more

b. How often do you use a computer?

___Daily: over 2hrs/day 1-2hrs less than 1 hr/day

___Weekly ___Monthly ___Once or twice a year

c. Where do you currently use a computer? (*Circle all that apply*)

Home Work Library Other________ Do Not Use

d. How often do you play computer/video games? (Circle one)

___Daily: over 2hrs/day 1-2hrs less than 1 hr/day

___Weekly ___Monthly ___Once or twice a year

e. Which type(s) of computer/video games do you most often play?

____

Medical Status Form

Experiment participant: Please answer all questions honestly and completely. It will not be entered into your official health records and will be treated confidentially.

Roster Number: ____________ Date: _______________________________

1. Do you have any physical injury at the present time?
Yes ______ No ______

If yes, please describe.____

2. Have you had any surgery in the last two months?
Yes ______ No ______

If yes, please describe.____

3. Are you presently on a profile of any type? Yes ______ No ______

If yes, please describe your current limitations. ___________________________________

4. If the APFT (Army Physical Fitness Test) were held today, could you obtain a passing score on it? Yes ______ No ______

5. Have you had any type of eye surgery or eye injury? Yes ______ No ______

If yes, please describe. ___________________________________

NASA TLX   Definition of Task Demand Factor

Mental demand

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Physical demand

How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Temporal demand

How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Performance

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Frustration level

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort

How hard did you have to work (mentally and physically) to accomplish your level of performance?

NASA-TLX Mental Workload Rating Scale

Please place an “X” along each scale at the point that best indicates your experience with the robot controller you just used.

<u>Mental Demand</u>: How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc)? Was the mission easy or demanding, simple or complex, exacting or forgiving?

Low High

<u>Physical Demand</u>: How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the mission easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Low High

<u>Temporal Demand</u>: How much time pressure did you feel due to the rate or pace at which the mission occurred? Was the pace slow and leisurely or rapid and frantic?

Low High

<u>Performance</u>: How successful do you think you were in accomplishing the goals of the mission? How satisfied were you with your performance in accomplishing these goals?

Low High

<u>Effort</u>: How hard did you have to work (mentally and physically) to accomplish your level of performance?

Low High

<u>Frustration</u>: How discouraged, stressed, irritated, and annoyed versus gratified, relaxed, content, and complacent did you feel during your mission?

Low High

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Appendix C. Questionnaire Results

This appendix appears in its original form, without editorial change.

DEMOGRAPHICS

SAMPLE SIZE = 31

1. General Information

a. Age (yrs): 25 years (mean) - (range is 20 to 34 years)

b. Gender: _25_ Male _6_ Female

c. Handedness _27_ Right _3_ Left _1_ Both

d. Uniform size:

Number of Responses											
XS	**XS-Long**	**Small**	**Small-reg**	**Med**	**Med-reg**	**Med-long**	**Large**	**Large-reg**	**Large-long**	**Large-x-long**	**NR**
1	1	2	2	7	6	5	1	1	3	1	1

e. Height (inches): 70 inches (range is 64 to 75 inches)

f. Do you have corrected vision? _23_ None _6_ Glasses _2_ Contact Lenses

g. Do you have any type of color blindness? _31_ No _0_ Yes

h. Do you have any hearing loss or other impairments? If so, please describe. _29_ No _2_ Yes

i. Do you currently have any skin sensitivities on your torso (chest, waist) that might be irritated by wearing a haptic belt (for example, poison ivy, insect bites, rash, etc? _30_ No _1_ Yes

j. On a scale from 1 to 5, how ticklish are you (chest/waist area), with 1 = not at all and 5 = very ticklish?

Mean
2.41

2. Military Experience

a. How many years have you been in the military? 40 months (mean) (range is 7 to 114 months)

b. Current rank: 1 E-1 1 E-2 2 E-3 15 E-4 6 E-5 1 E-6 5 OCS

c. MOS: 6 09S 6 11B 1 19K 1 35N 1 42R 1 68W 11 89D 1 90A
1 91B

d. Combat deployments (Iraq, Afghanistan, etc.) and the length (Years / Months) of each.

LOCATION	MEAN (Length/Months)
Afghanistan	11 months (3 people)
Iraq	14 months (5 people)
Kuwait	10.5 months (2 people)

e. Do you have operational experience in urban terrain? 7 Yes (14 months-mean) 24 No

f. Do you have operational experience in reconnaissance situations? 6 Yes (12 months-mean) 25 No

g. Have you any experience with military robots? If so, what type and purpose?

TYPE	PURPOSE
Talon (9 people)	EOD, Recon/RSP, operations, training
Pacbot (7 people)	EOD, Recon/RSP, operations, training
Pacbot 510	EOD
EOD Robots	IED
Mini 310	EOD
All IRobot Products	EOD
M2 Tallon	Recon, uncovering items, collecting evidence
310, 510, Andros	

3. Educational Data

a. What is your highest level of education received? Select one.
0 GED
9 High School
6 Some College
14 Bachelors Degree
2 M.S/M.A
0 PhD or other doctorate

b. If applicable, what subject is your degree in (for example, Criminal justice)?

c. Psychology (2), Health & Physical Ed, English, Economics (2), Comparative Literature, Mechanical Engineering, Finance (2), Marketing, Communication Sciences & Disorders, BioMed, Biology, Piano Performance/Music Education, Business Admin/Management (3), Nursing, Criminal Justice (3), History, Auto Diesel Mechanics

4. Computer Experience

a. How long have you been using a computer?

_0_ Less than 1 year _0_ 1-3 years _2_ 4-6 years _4_ 7-10 years _25_ 10 years or more

b. How often do you use a computer?

_31_ Daily: _10_ over 2hrs/day _7_ 1-2hrs _6_ less than 1 hr/day
_0_ Weekly _0_ Monthly _0_ Once or twice a year

c. How often do you play computer/video games?

_14_ Daily: _3_ over 2 hrs/day _7_ 1-2hrs/day _4_ less than one hr/day

_5_ Weekly _5_ monthly _6_ once or twice a year _1_ Never

d. Which type of computer/video games do you most often play? (ex: first person shooter, driving, etc)

Comments	**No. of Responses**
First person shooting	23
Driving	5
Multiplayer campaign	1
Strategy (map based)	4
Strategy (turn based)	1
Fighting	1
Role play	2
RTS	2
MOBA	2
MMO	1
Sandbox RPG	3
Platformers	1
Arcade type games	1
Puzzle	5
Candy crush	1

Bubble witch	1
Minion rush	1
Temple Run	1
Snood	1
Sports	2

5. Medical Status Form

a. Do you have any physical injury at the present time? _1_ Yes _30_ No

If yes, please describe: Lower back/hip

b. Have you had any surgery in the last two months? _0_ Yes _31_ No

c. Are you presently on a profile of any type? _2_ Yes _29_ No

If yes, please describe your current limitations: No running, jumping, rucking, lifting; no contact, climbing – everything at my own pace.

d. If the APFT (Army Physical Fitness Test) were held today, could you obtain a passing score on it?

_31_ Yes _0_ No

e. Have you had any type of eye surgery or eye injury? _1_ Yes _30_ No

If yes, please describe: PRK Corrective Surgery

REVIEW OF GLOVE ROBOT CONTROLLER SYSTEM
COMFORT AND USABILITY

SAMPLE SIZE = 30

1. Using the following scale, please rate the following aspects of the glove.

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

	MEAN
Comfort of Glove	6.21
Ability to control the robot using the glove in general	4.90
Ability to control the robot using the glove: MOVE FORWARD	5.67
Ability to control the robot using the glove: MOVE BACKWARD	5.63
Ability to control the robot using the glove: STOP	4.20
Ability to control the robot using the glove: LEFT TURN	4.73
Ability to control the robot using the glove: RIGHT TURN	4.63

Comments	**No. of Responses**
Comfort/Fit	
Very good and well controllable robot.	1
Very comfortable and natural.	5
Good material.	1
Fairly comfortable.	1
Fit just fine.	2
I think the lighter you can make it the better.	1
Different sizes would be good.	1
A more breathable material would help. When I removed the glove my hand was extremely sweaty.	1
Felt comfortable to wear but need disable/pause button so you can relax arm.	1
The glove itself was comfortable but the position you have to keep your arm and hand in could be tiring over extended time.	1
Wrist/forearm gets tired after prolonged use.	1
Was not sure of range of control. A few times the robot would continue the last command, despite me giving another order, because I was out of its effective communication range.	1
Glove might be too small for some people. A larger glove with a compression strap may be better.	1
Glove was a little too big for my hand (women's small) so the controls felt sloppy. It	1

Comments	No. of Responses
did, however, stay secure. My hand was not too hot or too cold. The material used did not scratch or itch. Having to hold my arm parallel to the ground was tiresome.	
Interchangeable with personal equipment.	1
A little too touchy.	1
General Robot Control	
Basic forward/backward went well.	1
Just need more practice.	1
The control needs to be very precise in our job field. Since we are working with explosive devices, every movement needs to be deliberate.	1
I don't know what type of engineering goes into this but I was overall very impressed. That being said, the robot could not multitask as well as the controller. If found it difficult to turn while going forward and backward. It was kind of uncomfortable standing and holding my arm out. I found myself holding my glove hand with my non-glove hand which helped.	1
The robot could drive backwards in circles but not forward. Forward command would cancel turn left/right commands. The robot could turn and move backwards at the same time. Speed was also more difficult to control. It seemed to move faster backwards.	1
It seemed to have trouble turning and driving forward at the same time, although I did not see the same problem when driving in reverse and turning.	1
The reverse was kind of shoddy sometimes.	1
Improvements with turning while moving.	1
Brake command or feature to stop from moving forward/backward.	1
Needs a better stop position gesture.	4
Turning was sometimes jumpy.	1
System is a little jumpy in wet grass with the gloves – especially with the right/left turning.	1
Left and right need to have a bit higher sensitivity.	1
Very sluggish when turning right.	1
A little less sensitive.	3
Controls were too sensitive, so making small adjustments was difficult. The robot would be better if its responses weren't as sudden.	1
Make robot more sensitive to movement.	1
Very jumpy/unresponsive when walking and using the robot at the same time.	1
When distracted, the glove required that I stay focused on keeping my hand level so it wouldn't move. I would have preferred if there was a halt (totally stop the robot) function by making a fist.	1
Think there should be a switch to activate.	1
Glove would not react correctly and would change reaction indiscriminately.	1
Glove wasn't responsive enough (joystick on controller is immediate).	1
Moving the index and middle finger to turn is not as intuitive as I originally thought it would be.	1

Comments	No. of Responses
Use full hand motion.	1

2. Using the following scale, please rate the level of difficulty for each robot control event that you performed.

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN
Narrow Gap: Guiding the robot through a gap in engineering tape	5.07
Zigzag: Guiding the robot through a zigzag course	4.47
Figure 8: Guiding the robot around wooden logs	4.77
Stationary object: Guiding the robot to a stationary object, then backing to another point	4.87

Comments	No. of Responses
Narrow Gap	
Very easy once able to control robot.	1
The sudden turns and acceleration from the glove made the precision moving difficult, but overall the course was more easy than difficult.	1
Hit the flags a few times but overall easy to maneuver quickly.	1
Was easy except for the reverse.	1
Some of the flags were bent which made getting around them difficult.	1
The biggest problem was from having to stop to turn while moving forward.	1
I had to stop the robot in order to turn it. I accidentally sent it forward when I was walking around the obstacle.	1
Depending on location, depth gets distorted.	1
If smaller, would be greatly improved.	1
Sometimes too sensitive.	1
Zigzag	
Good width, tight turns.	1
A little hard, but very capable of doing.	1
Turning was easy if I came to a stop before turning.	1
Not so much forward, but in reverse excellent.	1
Hard to turn quickly on a point without stopping to ensure accuracy and prevent loss of control.	1
The biggest problem was from having to stop to turn while moving forward.	1
Turn radius and sensitivity of glove made it difficult.	1
When I told the robot to turn sometimes it would turn more than I wanted.	1
It was slightly more difficult to position the robot because of less control of speed.	1
Tape was close together. Robot movements were not precise. Somewhat difficult.	1

Comments	No. of Responses
Hard not to hit the tape when turning.	2
The course was very narrow, which was the only difficult part about it.	1
Narrow flag gaps impede speed of movement.	1
Figure 8	
Very easy and capable of controlling.	1
Flags spaced fairly far apart.	1
Easy to maneuver.	1
Easy forward and back.	1
Great approaching.	1
Motions were more fluid in reverse.	1
Most difficult because getting the robot around the barrel, through the flags and then around the other side of the next barrel required I go slower which was difficult with the glove.	1
Stationary Object	
Very easy.	1
This portion was significantly easier with the glove as opposed to the controller.	1
Easy, but sometimes the object was hit.	1
Have to go easy to avoid hitting pole. Other than that it was easy.	1
Fast, simple and straightforward, but I couldn't see very well how close the robot was to the pole and the jerky controls make easing up to it more challenging.	1
Could not see the spatial distance between the robot and pole; therefore I was unsure if the robot could move further. Could see how this would have real world implications.	1
Normally our robots have cameras that help with depth perception, so doing it just by looking makes it difficult, and because there isn't a stop position it was hard to prevent it from moving.	1
Difficult without some sort of camera or sensor.	1
Reversing and turning requires some thinking as turning directions are reversed.	1
Without more familiarization it was hard to gauge the sensitivity of the robot to my motions.	1
Hard to make finer adjustments with the glove as far as slowly approaching an object goes.	1
Hard to keep robot still.	1
Too touchy.	1

3. Using the scale below, please indicate whether you agree or disagree with the following statements

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

	MEAN
"It was easy to learn the glove commands for robot control"	6.30
"It was easy to execute the glove commands"	5.50
"The robot responded effectively to commands"	4.63
"The glove is a good concept for robot control"	5.40
"The glove helped keep my attention on my surroundings"	4.03
"It was too time consuming to maneuver the robot through the obstacles"	4.90

Comments	**No. of Responses**
The glove will not affect surroundings because we will be watching the video screen which will have the majority of our attention.	1

4. The following questions have to do with the overall concept of this system. Using the scale below, please provide feedback with regard to the POTENTIAL usefulness of this capability, **assuming the system was developed to be combat-ready (reliable, rugged, lightweight, etc.)**

a. In your opinion, how likely is this technology to be useful for Army operations

1	2	3	4	5	6	7
Extremely unlikely	Very unlikely	Unlikely	Neutral	Likely	Very likely	Extremely likely

MEAN
5.60

b. If unlikely to be useful—why? If likely to be useful, what situations first come to mind?

Comments	**No. of Responses**
Advantages	
Everything.	1
Glove is easy to learn; not a lot of different controls.	1
Robots are always a useful tool for doing things remotely.	1
This concept would pair perfectly with use of the mini 310 on dismounted operations. Significantly easier to make fine adjustments, less jerky than the controller. In other words, I feel like I have more control with the glove.	1
Being able to focus on your surroundings.	1

Comments	No. of Responses
Easy to control and operate.	1
Easy control for someone who has had adequate training.	2
Keep soldiers safer from a distance.	3
Can cause a nice distraction.	1
Lightweight.	6
Smaller.	1
Compact.	1
Not bulky.	1
Can fit basically anywhere.	2
Single handed.	1
Still have a free hand to work with.	1
Easy to maneuver around; doesn't jerk.	1
Able to maneuver with one hand while carrying weapon in the other.	1
Frees up a hand and favors non-console playing user.	1
Having a glove means that no one has to carry an extra controller.	1
Controls are really easy.	1
The advantages are about the same as the controller.	1
Once fine tuned, it could be used effectively while saving space instead of having to carry an OCU.	1
Potential for more fine tuned movements.	1
Checking for IEDS.	1
Technology could be used on gripper which would make movements more fluid.	1
Situations	
All.	1
Anything to call for the use of other hand makes this advantageous.	1
For remote operations.	1
Any situation where you wouldn't want to send soldiers into a dangerous area.	1
For recon.	2
Searching for IEDs (cars, buildings, and other dangerous situations).	4
IEDs in hard to reach places, spying.	2
EOD; clearing through hallways and rooms.	1
EOD as well as engineers.	1
EOD, pushing ahead of patrol like with UAV.	1
Tight spaces.	1
Bombs.	1
Could be used when suspicious objects/locations need to be examined and there exists a high probability of casualties.	1
Perfect for dismounted operations and may even be easier in a mounted environment. I would have to experience that to know for sure.	1
Dismounted mission or something similar where packing light is a must!	3
Only one hand available.	1
Manipulating arm/gripper on robots.	1

Comments	No. of Responses
Problems/Issues	
Just need more hours of practice. Being EOD and doing extensive training on robots with controllers I am amazed at how quickly I was able to become proficient at making small adjustments. With practice I would be significantly better with the glove.	1
If the user were to make any big unnecessary movement it would send the robot off in every direction in which the hand goes. It takes a steady had and concentration that not everybody has.	1
Lack of accuracy/control.	1
The glove made it hard to keep the robot still.	1
Using the glove to drive the robot is unnecessary. Driving a robot is more easily done with a simple joystick/toggle. Also if you have to immediately use the gloved hand you would have a range robot.	1
Has to be constant attention to make sure it moves correctly.	1
Harder to control with the glove due to unnatural twitching in the hand.	1
Signal between glove and robot is sketchy.	1
Needs to be extremely precise for our job field.	1
Precision control with the glove is difficult. Having the glove on means the operator can't do anything else with that hand.	1
Sometimes movements are not precise. Cannot move a tiny bit forward.	1
Cannot make as fine of adjustments with the robot and not good at turning while driving.	1
Software bugs.	1
Sluggish response.	1
Does not provide operator with a full field of vision and problems turning through thick grass.	1
How do you quickly transition from robot operations to other tasks? How durable is the glove? If you fall or stumble you will move the robot.	1
To touchy on the glove.	1
Very sensitive to hand movements.	1
Sensitive at times and not sensitive at others.	1
Better rest position.	1
Needs start and kill switch.	1
Arm gets tired.	2
Having to keep hand orientated flat (maybe try to include a robot lock so you can use your hand if you need it).	1
Not multitasking well (turning while driving forward or reverse).	1
Extremely jumpy/unresponsive when walking and using the robot at the same time.	1
Turning left and right (more sensitive).	2
Can't focus on situation at hand.	1
Other uses/Control functions – CUAV, other ground robots – camera gripper	
Regardless of the method of control, the robot could be used for scouting and recon,	1

Comments	No. of Responses
payload delivery through small passages, and as the purposeful sacrifice when trying to set off an IED that's been discovered. Could also be used as sound weaponry (have the robot play screeching noises to disorient enemy or play the sound of footsteps, sneezing or the charging of a rifle so as to mislead the enemy).	
It was easier to control it when driven backwards.	1
Driving backwards right finger turns it right.	1
Driving forward hurt my brain; mental gymnastics are unnecessary.	1
Rather than changing how to move the robot, I feel that improving the camera and signal as well as operating the arm and gripper is much more necessary.	1
How will you be able to see the camera? It needs a lightweight compact video system.	1
I personally see the glove as a hindrance. There is much more that can be done with a remote. I think the idea is alright but it is impossible to judge without cameras or an aim/gripper.	1
Add a camera to the top.	2
Cameras and a gripper arm are an absolutely must for EOD.	2
Without use of cameras this technology is useless to EOD.	1
The control system could be applied to other robots (UAVs, heavy construction equipment, cameras). It could also be used to interface with computers. The glove could replace a keyboard and mouse.	1
It could be useful in other robots, such as the ones we use IF it is developed properly. There are a lot of controls we have on our OCUs and it could be problematic trying to fit all those controls onto a glove.	1
Needs an on/off button on the glove to prevent unwanted movements.	1
Sensitivity adjustment.	1
Use to disarm EODs; gather information/recon.	1
Explosive devices.	2
Another glove on other hand with more controls would be neat. Maybe incorporate thumb, ring, and pinky fingers, rotating of wrist as well.	1
I would be interested with trying this with the Talon and a laptop size screen. Also would like to try a glove that worked as a turret/gripper. This would be perfect with the mini 310.	1
I would like to see this technology used in manipulating robot's arm.	1
Maybe a switch in order to switch the glove from drive to gripper.	1
Would like to see a grabber and clippers on the robot as well.	1
Make the starting point of the hand when you turn it on the neutral position.	1
Recon.	1

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REVIEW OF GLOVE IMT SYSTEM (PL ROLE FEEDBACK)

SAMPLE SIZE = 30

Comfort and Usability

1. Using the scale below, please rate the following aspects of the glove.

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

	MEAN
Comfort of Glove	5.50
Ability to use the glove in general for hand arm signals	5.31
Ability to use the glove: FREEZE	6.00
Ability to use the glove: DOUBLE TIME	5.11
Ability to use the glove: RALLY	5.67
Ability to use the glove: DANGER AREA	2.85

Comments	**No. of Responses**
Fit well.	3
Comfortable.	3
Very good (just needs to work every time).	1
Rally and freeze worked well.	1
A little more elastic fiber for winter gloves (to wear outside of glove).	1
It fit over watch/under ACUs comfortably, but was a little warm, which was distracting.	1
Should be more form fitting.	1
Different sizes.	2
A little tight.	1
Fit well but is a little bulky. The transceiver and power pack are also bulky.	1
Kind of heavy and thick.	1
A smaller glove.	1
Too big for female hand; needs to be adjustable.	1
Gloves would probably have to be fitted to specific users.	1
Make sensors interchangeable with different gloves or personal equipment.	1
Make sensors a little more sensitive.	1
I experienced frustration and less success because the glove would not register one of the functions. There was a delay in between when I gave the command and when he received the command. It also took a few seconds for him to remember which vibration series was which command.	1

Comments	No. of Responses
Need instructions on exact hand placement.	1
Hand arm signals were difficult to trigger.	1
A lot of hand gestures either didn't work or were hard for the other person to receive.	1
Some soldiers have limited range of motion.	1
Danger area and rally wouldn't work for me (one would work while the other did not; then they flip flopped).	1
Didn't always work.	1
Specific location of fingers for danger area made it difficult to use.	1
Danger area hand signal not working.	5
Danger area has to be perfect, not idle.	1
The danger area and double time is called are too touchy; it's hard to get it to work.	1
Danger area and double time did not work.	3
Double time was too temperamental. Took me a good minute to get my fingers in the right position before the rest felt anything. Danger area was also similar in response time.	1
Make it more accurate.	1
Long cord seems like a nuisance; wireless would be better.	1
I could see a problem with the transmitting unit on the belt getting in the way once you are in full kit.	1
Felt stuff digging into back of hand.	1

General Feedback

2.a. Using the scale below, please indicate whether you agree or disagree with the following statements

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

	MEAN
a. "It was easy to learn the glove commands for hand arm signals"	6.20
b. "It was easy to execute the glove commands"	6.97
c. "The glove is a good concept for hand-arm communications"	5.63
d. "The glove helped keep my attention on my surroundings"	5.40
e. "The glove sent the signal easily the first time"	4.17
f. "I prefer to use regular arm and hand signals"	3.77
g. "The glove is preferable to regular arm and hand signals for some situations"	5.30
h. "The glove concept has a lot of potential for operational usefulness"	5.83

e. Not for "danger zone."	1

b. Please list any situations that the glove communications system could be useful.

Comments	**No. of Responses**
Many situations, if it worked.	1
Silent operations.	1
Covert missions.	1
Dismounted patrol; particularly in cover operations.	1
Patrolling.	2
Patrols/recon missions where silence and attention is needed.	1
Working in large area with squads split up and not in line of sight.	1
Squad size movements for quicker reaction.	1
Combat area.	1
When operating around crowds or vehicles.	1
Situations where space between PL and point where you would rather have them looking at their surroundings rather than constantly looking back.	1
Night operations to help with noise discipline and point man awareness.	2
During low visibility conditions or during fire fights.	1
Movement when silence is needed.	2
When line of sight is obstructed or if operational demands that your soldier's attention is elsewhere.	1
Missions that require complete eye contact.	1
Anytime vision is impaired, i.e., night, smoke.	1
Limited visual situations (forest, urban environment).	1
Breaching buildings.	1
If the glove was more form fitting it would be more responsive and less temperamental. It would definitely slow down mission if I was trying to figure out if those wearing vests received the signal.	1
Depends on if it sends false signals while gripping a weapon.	1

Overall Concept

3. The following questions have to do with the overall concept of this system. Using the scale below, please provide feedback with regard to the **POTENTIAL usefulness** of this capability, **assuming the system was developed to be combat-ready (reliable, rugged, etc.)**

a. In your opinion, how likely is this technology (use of glove for Army hand arm signals) to be useful for Army operations, if it was improved to be combat ready?

1	2	3	4	5	6	7
Extremely unlikely	Very unlikely	Unlikely	Neutral	Likely	Very likely	Extremely likely

MEAN
5.91

b. If unlikely to be useful—why? If likely to be useful, what situations first come to mind?

Comments	No. of Responses
Advantages	
Easy to use.	2
Quicker response time.	2
Quiet.	3
Silence ensures members feel pulse and can stay in contact with surroundings.	
No vision required.	1
Eye contact is not needed to obtain commands.	1
When you have to be quiet or in a long convoy.	1
Non verbal cues.	1
Good in decreased visibility or obstructed line of sight situations.	1
Faster communication.	1
Communication without line of sight.	2
Keeps you attention on what is in front of you.	1
No need for soldiers to look back at the one giving commands.	2
Allows soldiers to be more aware of the surroundings on patrol.	1
Maintain better situational awareness.	3
It eliminates the attention one has to take to look back which can be diverted towards a deeper awareness of their surroundings.	1
No need to look around or behind for hand signals.	1
Keeps the team alert and conscious of commander’s decision.	1
Point man awareness and PLs ability to communicate with point man.	1
Improves communications in the operation environment.	1
Eliminates need for more commands.	1
Soldier gets the command while he/she travels tough terrain or obstacles.	1
If a unit is doing a patrol, everyone receives the signal at the same time rather than a few minute’s delay.	1
Extremely useful in nighttime environments or inclement weather where visibility is low.	1
Problems/Issues	
The glove can work great sometimes and touchy at others.	1
Glove was difficult to use.	1

Comments	No. of Responses
Potential malfunctions.	1
What is to prevent it from sending a signal by accident? If you clinch your hand or point to the ground it could send the wrong signal at the wrong time.	1
Possibility of glove malfunctioning and not providing signals.	1
Needs to be durable and have good range.	1
Power consumption could be an issue.	1
Connectivity issues.	1
Sometimes the signal doesn't go through, so relaying the message needs some work.	1
Vibration is loud.	2
Delay in which command given/received.	1
Danger area signal wouldn't catch.	2
Certain hand signals have issues being read.	1
Some commands are difficult to perform precisely.	1
Slight delay between a command and vibration as well as the vibration of "freeze" and double time need to be varied more. Also, appearance could be worked on.	1
Glove needs to be adjustable for all hand sizes to allow proper connections for the signals.	1
Compatibility when in full kit, and just having another piece of equipment to have to maintain.	1
Needs to be more compact, smaller battery packs, and no cords.	1
Equipment not communicating well.	1
Needs to work every time.	1
Glove doesn't always send signal the first time.	1
Not all hand signals work all the time.	3
Not all signals work on the glove.	2
Possible tighter fit for users with smaller hands.	1
Battery pack was bulky. I had to fully close and tighten my fist for rally command.	1
Glove placement and movement is very specific. Might have issues being used in other stances.	1
Will it be waterproof? I think this is important since you never know where the mission will lead.	1

c. Can you think of other situations or commands where using the glove for communications could be useful (assuming combat read) (e.g., shift fire, initiate ambush, load up, etc). Please list potential uses/commands.

Comments	No. of Responses
Has potential in all areas.	1
It would be useful for any situation until you come under fire.	1
Man down and specifying the wounds/pain location.	1
All other commands would be useful as well.	1

Comments	No. of Responses
Breach room, gear up, am busy, stay down.	1
Slow down, get down, prepare for actions, move out, shift fire, lift fire, cease fire, increase intervals, decrease intervals.	1
I would not recommend or shift fire/lift fire.	1
Adding shift fire commands, when crossing a phase line.	1
Shift fire, move forward, other tactical positions such as column, wedge, etc.	1
Shift, lift fire, anytime it s loud and focus is on an objective.	1
Loading and unloading.	1
Make every person have a glove.	1
Integrate buzzer into glove.	1
Everyone in unit, including glove user, needs sensor. That way solder knows if his signal went through.	1
Useful in silent ops or ops against English speaking populations.	1
Squad attacks.	1
Load up and initiate ambush would have positive uses.	1
Any situation where noise discipline is necessary or vision is impaired.	1
Almost any situation where a verbal command produces unwarranted noise or can eliminate a diversion from the mission.	1
A way to signal to one group to do one thing and another group to do another. Such as one squad flank left and one squad flank right. Right now everybody would be given the same tasks.	1
The wrong signal being transmitted. That can be fatal to some soldiers possibly.	1
Pretty much anything that we have hand and arm signals for now.	1

REVIEW OF OCU ROBOT CONTROLLER SYSTEM

SAMPLE SIZE = 27

Comfort and Usability

1. Using the following scale, please rate the following aspects of the glove.

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

	MEAN
Size of OCU	6.15
Shape of OCU	6.31
Weight of OCU	6.27

Comments	**No. of Responses**
Overall felt comfortable and natural.	1
I really don't have any. I am familiar with a similar system.	1
Worked out perfectly.	1
Much more intuitive.	1
I liked being able to do forward/backward and right/left at the same time.	1
Perfect size due to most soldiers playing video games.	1
For the task the physical shape was fine. But neutral rating because this would be dependent upon the overall objective.	1
The shape was correct for its size, but it's too big.	1
Lighter is always better. So if it could be improved, just continue getting lighter.	1
Outside the sticks, what were the functions of the other buttons?	1
Make it less reactive to motion on initial stick depression.	1
Cameras so you do not need line of sight.	1
It's hard to rate the OCU without the camera/video element because that is an important part of the OCU.	1

	MEAN
Ability to control the robot using the OCU in general	6.48
Ability to control the robot using the OCU: MOVE FORWARD	6.41
Ability to control the robot using the OCU: MOVE BACKWARD	6.44
Ability to control the robot using the OCU: STOP	6.33
Ability to control the robot using the OCU: LEFT TURN	6.48
Ability to control the robot using the OCU: RIGHT TURN	6.48

Comments	**No. of Responses**
Easy to use.	2
The controller is the best.	1
The controls are fluid and intuitive.	2
Easier to make precision controls with. When I let go of the controls entirely, the robot stopped which was easier than trying to keep my hand level.	1
Improved range could affect the ability to control the system from further distances.	1
Have all directional controls on one joystick so you can free the other one up for arm/camera or gripper movement.	1
Using two sticks for directional movements helped.	1
The controller is more difficult to perform fine movements which are essential to the EOD mission. It is difficult to control the speed between fast and slow.	1
OCU is large. Where do I stow it? Is it durable? Can you make it lighter?	1
Sometimes the robot lost signal and moved on its own.	1
Movement is jerky due to nature of tracks. More tires on tracks would solve this.	1
There needs to be a way to stop/prevent movement. I really liked that the speed was based on the pressure placed on the controls.	1

General Feedback

2. Using the scale below, please indicate whether you agree or disagree with the following statements.

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

	MEAN
"It was easy to learn the OCU commands for robot control"	6.85
"It was easy to execute the OCU commands"	6.74
"The robot responded effectively to commands"	6.15
"The OCU is a good concept for robot control"	6.59
"The OCU helped keep my attention on my surroundings"	5.56

Overall Concept / Operational Relevance

3. The following questions have to do with the overall concept of this system. Please provide feedback with regard to the POTENTIAL usefulness of this capability, **assuming the system was developed to be combat-ready (reliable, rugged, lightweight, etc.)**

a. Using the scale below, how likely is this technology to be useful for Army operations assuming combat ready?

1	2	3	4	5	6	7
Highly unlikely	Somewhat unlikely	Unlikely	Neutral	Likely	Somewhat likely	Highly likely

MEAN
6.48

b. If unlikely to be useful – why?

Comments	No. of Responses
As long as it has a very long range it is useful. If you have to stand close to the robot then it's pointless.	1
Needs antipersonnel weapons.	1
The only drawback is having to carry/keep track of the controller.	1
Noisy, large, not able to perfectly control.	1
The OCU is already in use but I liked the glove better.	1

c. If likely to be useful, what situations first come to mind?

Comments	No. of Responses
Every situation in which I can think of this would be useful.	2
Mounted or dismounted.	3
We mostly use the Xbox controller.	1
We already have a system that uses a similar controller but I liked that this one was wireless. The video component needs to be factored in.	1
Easy control for gamers.	1
Looking for IEDS in cars or buildings, as well as around sharp corners in urban operations.	3
To explore places where we wouldn't want to send soldiers.	1
Using as system before movement, like UAV.	1
EOD.	3
EOD and object interrogation.	1
Can be used in CBRN environments. Can access buildings through mouse holes and windows to provide intelligence.	1

Comments	No. of Responses
Situations that are very dangerous to humans, i.e., when enemies use gas.	1
Recon for combat arms units.	2
Scouting.	1
Engaging the enemy.	1
Raiding houses.	1
Disarming.	1
Clearing rooms.	1

d. Advantages.

Comments	No. of Responses
Ease to use and maneuver.	3
Easier to learn due to most people playing video games.	1
Very familiar.	2
I’ve had countless hours of practice with the OCU over the glove.	1
This is already a used method so training would be minimal.	1
Simpler controls.	1
Smaller than traditional OCUs; light, smaller, easy and familiar.	1
Lightweight.	1
Wireless.	1
Easy to replace if destroyed.	1
Keep soldiers safe from a distance searching for IEDs in cars and buildings.	1
Sending robots in dangerous settings kept soldiers safe.	2
Controller is intuitive.	2
While gathering information on surroundings.	1
Better responses made for better performance of task.	1
Can be easily stowed/placed down for transitioning to other tasks.	1
Doesn’t require as much attention as the glove (i.e., the current angle of your hand).	1
Don’t need to remove your combat gloves in order to operate the controller.	1
Better control of movement through the glove.	1
Only the enemy needs to die to ensure freedom and democracy will flourish.	1

e. Situations.

Comments	No. of Responses
All.	1
Clearing rooms.	1
Useful anywhere a robot or UAV is employed. It cannot be used while moving.	1
Dismounted or any situation where a robot is needed.	1

Comments	No. of Responses
Both mounted and dismounted.	1
Recon.	1
Dangerous situations or times when humans would be ineffective/inefficient, i.e., very hot days.	1
Silently dropped off by automated quadracopter.	1
EOD.	2
Patrol.	1
IED investigation/detonation.	1

f. Problems/issues.

Comments	No. of Responses
Nothing that I could tell.	1
Just needs to be fine tuned.	1
Range capabilities are a little short.	1
Camera! This research is really inconclusive without the camera component. It's easy to say lightweight but without the video it's hard to say that it would remain that way.	1
Is it protected from EMPs? What range does it have? Does it require maintenance/servicing/inspections? Under what environmental conditions can it operate? Does it need to be stowed in a special case? How long will the batteries last?	1
Special displacement of operator in accordance with robot.	1
Needs both hands.	1
Somewhat noisy.	1
Could malfunction during a task.	1
To reactive to analog stick depression.	1
The only drawback is having to carry/keep track of the controller.	1
The problem with using controllers is that the movements are jerky. They are not nearly as fine as with the glove.	1

REVIEW OF TACTILE HARNESS SYSTEM

SAMPLE SIZE = 30

Comfort and Usability

1. Using the scale below, please rate the following aspects of the glove.

1	2	3	4	5	6	7
Extremely negative	Very negative	Negative	Neutral	Positive	Very positive	Extremely positive

	MEAN
Comfort of Tactile Harness	5.17
Adjustability of Tactile Harness	4.77

Comments	No. of Responses
Was fine.	1
Good fit.	1
Very good; not hard to use or get.	1
Overall comfortable.	5
Easy to adjust.	1
The harness fit comfortable around the torso area.	1
The harness itself was comfortable but the pack with it was too heavy. In dismounted operations it is critical to reduce weight.	1
Make lighter.	2
Harness fit well but the utility belt was hard to wear my uniform in, roll in, low crawl, etc.	1
Use belt and snaps.	1
Better belt. Something to secure pouches so they stay on your back and don't rotate to the front of you.	1
Maybe something integrated into the uniform jacket.	1
Utility belt didn't fit under my blouse. The pouches slid around, which was cumbersome.	2
More adjustable harness and be able to store the controller in your assault pack on strap on the vest.	1
Although there were some elements that were adjustable, it seemed to be in the wrong place. Not to mention both the belt and harness were too big on me even on the smallest setting.	1
Better fitting.	1
Smaller belt; easier to adjust.	2
Weight did not feel balanced. Sometimes felt loose and not secure.	1

Comments	No. of Responses
The only real issue is the receivers attached to the belt. I feel that they should be less bulky for better comfort.	1
Bulky and uncomfortable.	2
Belt system was a little heavy and in the way.	1
Belt is too bulky, as well as the cord.	1
In addition to standard gear that would be worn, it would be annoying to adjust or remove, it could also be restrictive.	1
Different sizes.	1
Harness seems a little small, so I think the system should come in a variety of sizes for adjustability purposes.	1
Make a couple sizes for big and small soldiers so the comfort and fit is not a problem.	2
Vest felt small.	1
Current size is not conducive to smaller body types.	1
Needs to be smaller or tighter for smaller people.	2
Big; make smaller so it's more comfortable.	1
Tighter to your body.	1
Replace the hook and loop fasteners with fasteners of a different type.	1
I realize the technology is new and the harness is a prototype, but if they can work on making the batteries smaller.	1
Battery packs are too large. One flat battery pack would work better.	1
Batteries kept weighing down belt making it difficult to tighten.	1
Needs to be wireless.	1
Wires at the bottom dangle; impede physical movement when semi-prone.	1
Wires kept getting in my way during the obstacle course.	1
Reeks of bacteria and the sweat of many men.	1
Velcro wore out after multiple uses.	1
Maybe something more than just Velcro for prolonged mission.	1
Velcro on straps needs to extend the length of the tightening strap.	1
More Velcro.	1
Maybe a buckle or something of that nature would be better.	2
Have adjustable buckles over Velcro.	1
Front pouches slid around.	1
Controller fell out of pouch. Would not fit in pouch.	1

2. Using the scale below, please rate the level of difficulty for the following.

Ease of Use

1	2	3	4	5	6	7
Extremely difficult	Very difficult	Difficult	Neutral	Easy	Very easy	Extremely easy

	MEAN
Ease of feeling tactor patterns in general	5.93
Ease of recognizing “DOUBLE TIME”	5.19
Ease of recognizing “FREEZE”	6.21
Ease of recognizing “RALLY”	6.30
Ease of recognizing “DANGER AREA”	5.15

Comments	**No. of Responses**
Very good system in general.	1
The ease of feeling tactor patterns was easy when it worked.	1
Great if the glove worked!	1
I was fairly easy to recognize after just a few minutes using and would become increasingly easier with more use.	1
When/if the signals transmitted, they were strong and clear.	1
The signals for freeze and rally were easily identifiable.	1
They are easy to recognize as long as you learn the vibrations.	1
Took an extra moment to differentiate between freeze and danger.	1
The system (gloves) did not work for danger areas and double time.	2
Danger area rarely worked and on the occasions it did, needs to be more distinguishable.	1
I think danger area should vibrate in the back and then the front, instead of the opposite.	1
Very easy to feel patterns in this situation, but may be very difficult to detect while in combat.	1
Use other buzzer besides the front ones to diversify signal.	1
Double time not working.	1
Focus more in different areas. All of them involve the chest. Maybe some (upper back/stomach) or simpler to the rally.	1

3. Using the scale below, please rate the level of noise of the tactors.

1	2	3	4	5	6	7
Extremely noisy	Very noisy	Noisy	Neutral	Somewhat silent	Almost silent	Silent

MEAN
3.73

Comments	No. of Responses
Seemed a little noisy.	2
If I was going into a building and trying to be very quiet, I would not wear this because of the noise.	1
It was hard to tell if it is noisy or I am just too close. I don't know if you can really adjust without losing the ease of feeling.	1
The noise level should adjust based off mission's needs.	1
Little bit quieter would be a good thing, but very impressive.	1
Could definitely give away position in a quiet environment.	1
Vibration noise may be insulated when worn under tactical gear.	1
I did not hear the device. I only felt a strong vibration.	1
More power; could barely feel.	1
Helped with recognition of command, not stealthy.	1
Could hear from about 5 feet away.	1

4. The tactor noise is related to the strength of vibration. When (what situations) would tactor noise need to be very quiet?

It's not that bad.	1
While running recon, tactical missions.	2
Night operations.	7
Night missions with no gunfire.	1
Silent operations or when you simply don't want to draw attention to yourself.	1
Noise/light discipline situations would not work.	2
When trying to maintain noise discipline.	1
Particularly quite AO.	1
The distance that the noise could be heard would be good knowledge.	1
Through danger area.	1
It may interfere with communicating on a radio.	1
Patrols.	3
Woods patrol.	1
When using the element of surprise.	1
Halt.	1
Recon.	1
Ambush.	3

Comments	**No. of Responses**
On a capture mission.	1
Raid.	1
Stealth operations.	1
Covert mission.	2
Urban environment.	1

5. Were some patterns easier to feel than others? __16__ Yes __14__ No

6. What patterns were easier to feel?

Comments	**No. of Responses**
Only had 2 patterns; both were easy to identify once used to it.	1
They were all pretty easy to feel.	4
I was quicker to recognize the more simplistic patterns.	1
Just had to figure out which one does what.	1
Halt.	1
Danger.	1
Freeze.	10
Rally.	8
Rally felt like freeze.	1
Rally was easier to feel and unique.	1
Double time.	3
Buzzing needs to be stronger and more varied.	1
Longer and steady vibration.	1

General Feedback

7. a. Using the scale below, please indicate whether you agree or disagree with the following statements.

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral	Somewhat agree	Agree	Strongly agree

	MEAN
"It was easy to feel each tactile signal in general"	6.10
"It was easy to feel each tactile signal while walking"	6.20
"It was easy to feel each tactile signal while performing IMT maneuvers"	5.27
"The tactile signal should be stronger"	3.17
"The tactile signal was annoying"	2.33
"The tactile signal felt ticklish"	1.83

	MEAN
"It was easy to understand what each signal meant"	4.73
"I was very certain what each signal meant"	5.00
"I recognized each signal immediately"	4.87
"The tactile cues are a good means of silent communication"	6.17
"The tactile cues are too noisy for regular patrols"	2.73
"The tactile cues are too noisy for covert missions"	4.50
"The tactile cues are a good substitute when radios cannot be used"	6.17
"The tactile cues help keep my attention on my surroundings"	6.33
"The tactile cues can be a useful way for Soldiers to communicate"	6.23

b. Please list any signals that were difficult to recognize.

<u>**Comments**</u>	<u>**No. of Responses**</u>
None were given while exercising a specific movement.	1
Hard to distinguish different signals in general while on ground.	1
Double time.	3
Harness wasn't working properly.	1
Danger area.	3
Freeze.	1
Freeze during the crawls.	1
All when low crawling.	1

<u>**Operational Relevance**</u>

8. Given the potential advantages of a tactile system (e.g., light security, noise-free, intuitive directions), and assuming it was further engineered to be combat ready (rugged, reliable), how might the system be useful for the following? Please use the scale below.

1	2	3	4	5	6	7
Extremely ineffective	Very ineffective	Ineffective	Neutral	Useful	Very Useful	Extremely Useful

<u>**NIGHT PATROL / OVERWATCH**</u>

a. How useful are tactile communications in this situation?

MEAN
6.07

b. How can the tactile belt be used in this situation – by whom?

<u>**Comments**</u>	<u>**No. of Responses**</u>
All members.	5
PL.	3
PSG.	1
Infantry.	2
Special ops.	1
Soldiers patrolling.	3
Squad leaders.	2
Road marches and missions.	1
Front man in a line formation.	1
PL and point man should have the system. This would cut down on the noise levels during night movements. Once the point man receives the signal, he could utilize the conventional hand signal to let the rest of the team know the PL's intent.	1
Allow point man to focus more on surroundings and travel.	1
It can be used to control the movement of the element (stop, move, and get down). The PL would need to equip team leaders or every soldier with a harness.	1
No idea about night patrol/overwatch.	1
Belt can be used by an overwatch to help ground team avoid enemy.	1
In an overwatch, the belt could be used for a simple "check in" to maintain radio silence. Given there was a respond button on the harness.	1
Front scouts and the head of the wedge.	1
For keeping element of surprise.	1
When you have a patrol the one walk patrol wears the glove and relays information back to the other soldier.	1
Nighttime engagements.	1
When visibility is low.	2
Allows you to use hand signals when you can't see.	1
Great for silent, non-visual communication.	2
To communicate signals without having to talk.	1
By the combat MOSs.	1
Anyone giving signals to communicate effectively because hand signals can't be seen in the dark.	1
Everyone needs to use it that way; everybody knows the signal and no confusion at all.	1

c. How can the tactile belt be used – for what?

This belt is excellent for dismounted ops in an IED probability zone. It allows the soldiers to continue scanning and not worry about looking back every couple of seconds.	1
Silent communications.	4

Comments	**No. of Responses**
Signals are quiet and easy to learn.	1
For missions that require noise discipline.	1
So you don't have to use verbal commands.	1
When unable to see hand signals.	2
Communicating at night without the use of radios.	1
One-way communications.	1
For communicating with subordinate elements in the field.	1
For advanced interrogation of ticklish prisoners.	1
Patrols.	4
Send info about what the patrol sees.	1
Road marches.	1
Raids.	1
Maneuvering.	1
Remote commands using drones.	1
Overwatch.	1
Spread out.	1
Recon mission.	1
When visibility is low.	1
Tactical missions.	1
Any battle situation.	1
Better focus.	1

d. What are some useful commands?

Comments	**No. of Responses**
It covers the four basic commands.	2
Any and all.	1
Any command that we use hand and arm signals for.	1
Incorporate a command that identifies that something was found (IED).	1
Halt.	7
Linear danger area.	1
Danger area.	4
Double time.	6
Freeze.	9
Move out.	1
Get down.	1
Stand up.	1
Contact left/right.	1
Rally.	9
Fire.	1
Cease fire.	1
Shift fire.	1

Comments	No. of Responses
All IMT commands, but only if they are different enough to be easily discernible.	1
Hear something; see something; all secure; on the way back; and sound alarm.	1
Wedge.	2
File.	1
Column.	1
Staggered.	1

EOD

e. Using the scale below, please rate how useful tactile communications are in this situation.

1	2	3	4	5	6	7
Extremely ineffective	Very ineffective	Ineffective	Neutral	Useful	Very useful	Extremely useful

MEAN
4.41

f. How can the tactile belt be used – by whom?

Comments	No. of Responses
Everyone.	3
Any EOD member.	1
EOD team imbedded with infantry.	1
PL.	2
SL.	2
Team leaders.	3
Team leaders for team members to signal what's going on around them.	1
Team members.	1
Troops.	1
The technician could use it to communicate with the team leaders.	1
Good way of communicating with team leader to warn them of down range safeties.	1
IED inspector.	1
By EOD tech disarming ordnance. Communicate to his squad.	1
The person deactivating the ordnance.	1
Bomb defusing.	1
No idea about feasibility in EOD missions.	1
Unknown. No apparent application.	1
Send signals to the one disarming.	1
It would only be useful with us if we were imbedded with infantry.	1
I do not believe there is a use for this when running an EOD problem. It would be	1

Comments	No. of Responses
useful when mixed in with an infantry or SF unit.	
Early warning if there's hostiles closing in.	1

g. How can the tactile belt be used – for what?

Comments	No. of Responses
Silent communications.	2
EOD.	1
Informing EOD members.	1
To signal EOD team leader as to what the situation is.	1
Allow ED to communicate with the other unit.	1
So you don't have to keep looking back.	1
Early warning.	1
To let TL know what's going on if fired upon.	1
By the team leader to give commands to the rest of the team.	3
Team leader walking down on an incident with no radio.	1
If one-way communication is needed.	1
To make decisions regarding EOD.	1
Diffusing explosives?	2
One provides overwatch while the other focuses on the bomb.	1
Directions via remote.	1
For missions dismounted.	1
When on mission with combat arms.	1
Only for use with the infantry or SF guys.	1

h. What are some useful commands?

All commands.	1
The ones we used.	1
Halt.	2
Danger area.	5
Rally.	4
100 lbs, 200 lbs, victim detonated, command detonate, withdrawal.	1
Forward.	1
Withdraw.	1
Abort.	1
Left/blue vs. right/red.	1
Man on the right/left.	1
All clear.	1
Freeze.	5
Look around (secondary device).	1

If there was a way to program our own signals it may be more useful.	1
Found IED.	2
Cut the wire.	1
Fall back.	1
Double time.	1

i. Are there other situations that come to mind where this concept would be useful?

Checkpoints.	1
Anytime when noise discipline is necessary.	1
Any situation where normal communication is not feasible.	1
Possibly with long convoys where drivers get sleepy to decrease the chance of an accident from a driver falling asleep or zoning out.	1
Patrol.	1

j. If unlikely to be useful – why?

<u>**Comments**</u>	<u>**No. of Responses**</u>
It has to fit under combat equipment and it has to have a good range.	1
It does not seem as if there would be a need to be quiet in an EOD situation. There will already be security and noise discipline; is unnecessary.	1
It is very rare for an EOD team to operate in an area where silence is necessary or the belt would be used.	1
Just in our job field. By the time we get on scene it is well know that we are there.	1
Too bulky.	1
Glove doesn't work.	1
Depending on the frequency could mess with explosives.	1
Where the signal would be cancelled out by EMP (Citadel, Duke, etc.).	1
We mostly work out of our trucks; this would focus more on infantry.	1
Need both hands free as an EOD tech down range on a problem.	1
EOD is a support element and will typically be in the rear of the formation.	1
Maybe because of the noise.	1

k. Potential <u>**advantages**</u> of the system.

<u>**Comments**</u>	<u>**No. of Responses**</u>
It is concise communication.	1
Instant communication.	2
Allows PL to communicate with soldiers without the SL having to stop and take eyes off surroundings in front of them.	1
Keep soldiers attention on the mission.	2

Comments	No. of Responses
Situational awareness.	2
To keep team informed but the reality is that we always stay in line of sight and really close to our team.	1
Keeps you aware of what's ahead of you.	1
Easy to use.	1
Not having to look back saves time.	1
Easy to continue walking while taking commands.	1
Silent communication; quiet.	11
Noise discipline for night operations.	1
Reduces noise and allows the soldiers to focus their attention on other tasks.	3
Noise/light security.	1
Group communication when not in eyesight.	1
Eye contact is not needed for silent communication.	1
Able to communicate silently or without seeing who you are communicating with.	2
Quick.	1
Accurate.	1

l. Potential situations where the system might be **useful.**

Comments	No. of Responses
Night operations/patrols.	5
Observation posts.	1
Patrols.	7
Recon stealth missions.	1
Infantry.	1
Dismounted missions.	3
MOUT operations.	1
Tactical missions through woods and/or fields.	3
Not so much for covert missions.	1
When enemy contact is expected.	1
Any patrol where noise/light discipline is called for or vision is obscured by foliage.	1
Special teams/recon/scouts.	1
EOD.	1
Covert missions.	2
Ambush.	1
Invading a compound.	1
Sending someone down range on an incident where instant communication is key.	1
Loud firefights.	1

m. **Problems/issues** with using this system.

Comments	**No. of Responses**
How it would fit under body armor. Moving sensors to the sides would change the vibrations and also would interfere with the side plates on the body armor.	1
More time training with the system and adjustable vibration levels based on operations.	1
Buzzing needs to be unique and more forceful. 3 are sent to the chest and are easy to confuse.	1
When soldier could not feel vibration. Repeat of vibration.	1
Hard to remember which vibration is which.	1
Batteries are cumbersome in full gear.	1
Battery life.	1
System may be difficult to read after several hours of continuous operation.	1
Must communicate to all or none. No squad selector.	1
May be hard to distinguish signals when under stress.	1
Misunderstanding commands.	1
Some signals need to be more distinguishable.	1
Some commands don't work.	1
It would be noisy in a building or other quiet situations.	1
Pouches are a mess.	1
GLOVE.	1
Bulky.	1
Weight.	1
Waterproof.	1
Your testing methodology is flawed and unscientific.	1
Try coding AUGs for hand signals to get a higher success rate. One second delay to reduce false signals.	1
Could be difficult to distinguish commands if a lot area introduced.	1
Non-transmitting of signal.	1
Sensors not strong enough.	1
Malfunction in serious situation.	1
Frequency when comes to EOD.	1
Not practical for EOD on problem.	1
Loud.	2
Vibrations might be too loud for covert missions.	2
At the moment, awkward to wear.	1
Having to maintain the equipment.	1

REVIEW OF TACTILE MULTISENSORY NAVIGATION AND COMMUNICATION SYSTEM

SAMPLE SIZE = 30

1. Using the scale below, please indicate the extent to which you agree with each of the statements below. (The following questions will help determine the structure of the multisensory navigation and communication system.)

1	2	3	4	5	6	7
Strongly disagree	Disagree	Somewhat disagree	Neutral/ Undecided	Somewhat agree	Agree	Strongly agree

	MEAN
a. The tactile system should warn me with a tactile signal before I receive a communication	4.07
b. The tactile system should repeat the message until I have acknowledged that I have received it	4.53
c. The tactile system should repeat a message only once	3.77
d. The tactile system should be used for critical information that represents imminent danger	5.83
e. The tactile system should be used to communicate any command that could be conveyed through hand and arm signals	5.80
f. The tactile system should convey a sense of urgency of the communication	5.17
g. The tactile system should convey a sense of priority of the communication	5.23
h. It is easy to detect tactile communication while I am moving	5.67
i. It is easy to miss a message from the tactile system if I am focused on something else	4.03
j. I would like the ability to create my own commands that could be used with this tactile system (e.g., create commands based on unit SOPs)	5.73
k. A moving tactile pattern should indicate an action cue (e.g., get down, move out)	5.67
l. It would be confusing to receive more than one tactile message in a row	5.33

Comments	**No. of Responses**
h. Yes, but it is hard to say without gear on.	1

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M LAFIANDRA
RDRL HRS C
K MCDOWELL
RDRL HRS D
B AMREIN
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D HEADLEY

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